Control-Mode Quick Reference Guide

Step-Down Non-Isolated DC/DC

Texas Instruments

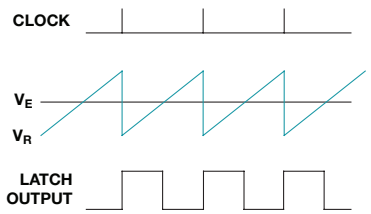
Overview

TI is active in the development of leading-edge control circuits to help engineers address specific design challenges. Since no control mode is optimal for every application, various control modes for non-isolated step-down controllers and converters are referenced with their advantages and how to learn more about each mode. The TI portfolio contains 12 types of control architectures for non-isolated TPS- and LM-series switching DC/DC converters and controllers.

Voltage Mode (VM)	Voltage Mode with Feedforward (VFF)	Peak Current Mode	Emulated Current Mode (ECM)	Internally-Compensated Advanced Current Mode (ACM)	Hysteretic
Constant On Time (COT)	COT with Emulated Ripple (COT with ERM)	D-CAP™	D-CAP2™	D-CAP3™	DSC Control™

Voltage Mode (VM)

Pulse-width modulation (latch output) is accomplished by comparing a voltage error signal (V_E) from the output voltage and reference voltage to a constant sawtooth-ramp waveform. The ramp is initiated by a clock signal from an oscillator. Good noise-margin performance is attained with a fixed ramp amplitude (V_R). Voltage regulation is independent of the output current. Voltage mode uses type-3 compensation addressing a double-pole power stage to support a wide range of output filter combinations for externally compensated devices.



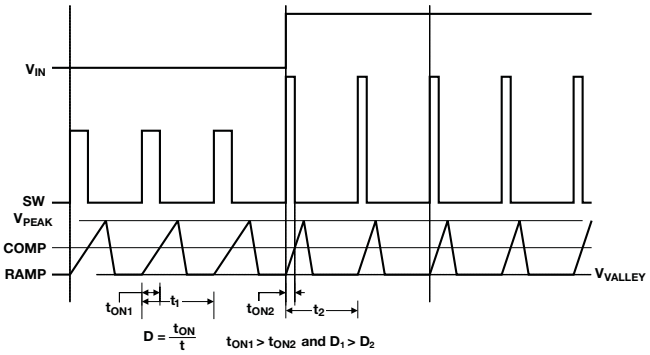
When to use: When a fixed, predictable switching frequency is desired. Also useful when wide output-load variations are possible.

Popular devices: TPS54610, TPS40040, LM22670

Learn more: Switching Power Supply Topology Voltage Mode vs. Current Mode (SLUA119)

Voltage Mode with Voltage Feedforward (VFF)

Similar to voltage mode, but ramp generator varies the PWM ramp slope with the input voltage at a constant ramp magnitude and delivers an instantaneous response to input voltage variations. The PWM does not have to wait for loop delays to change the duty cycle.



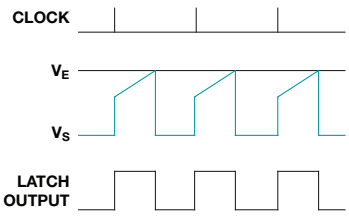
When to use: When a fixed, predictable switching frequency is desired. Also useful when wide variations of input voltage and output load are possible.

Popular devices: TPS40057, TPS40170, TPS56121

Learn more: Effect of Programmable UVLO on Maximum Duty Cycle Achievable With the TPS4005x and TPS4006x Family of Synchronous Buck Controllers (SLUA310)

Peak Current Mode

Pulse-width modulation (latch output) is accomplished by comparing a voltage error signal (V_E) and a ramp waveform (V_S) derived from the output current. The ramp is initiated by the clock signal. This mode offers fast response to output current changes. However, it can be susceptible to noise sensitivity at low duty cycles due to leading-edge current spike. It uses type-2 compensation addressing a single-pole power stage for externally compensated devices.



When to use: When a fixed, predictable switching frequency is needed with a lower parts count than the externally-compensated, double-pole voltage mode. Peak current mode uses a single-zero compensator which is easier to design than voltage mode's double-zero compensator.

Popular devices: TPS54620, TPS54336A, TPS54478, LM5140-Q1

Learn more: Understanding and Applying Current-Mode Control Theory (SNVA555)

Emulated Current Mode (ECM)

Similar to current mode, but employs a gated sample and hold circuit to capture current information emulated by measuring inductor voltage to estimate the ramp current. Eliminates the leading-edge spike issue of the traditional peak-current mode by allowing smaller duty cycles. Provides a clean current waveform when operating near the minimum on-time.

When to use: When low duty cycle is needed versus traditional current mode, without current noise susceptibility.

Popular devices: LM5116, LM5119

Learn more: Emulated Current Mode Control for Buck Regulators Using Sample and Hold Technique (SNVA537)

Internally-Compensated Advanced Current Mode (ACM)

Internally-compensated ACM is a ripple-based, peak-current-mode control scheme that uses an internally generated ramp to represent the inductor current. This control mode provides a balance between the fast transient response of non-linear control modes (D-CAP™, constant on-time, etc.) and the broad capacitor stability of other externally-compensated, fixed-frequency control modes (VM, CM). Internally-compensated ACM provides a fixed, predictable frequency and a simplified compensation selection to reduce external components.

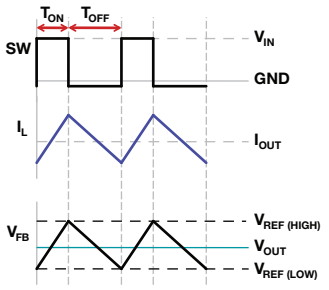
When to use: When fixed frequency and/or stack ability is needed with good output capacitor tolerance and a simplified compensation selection.

Preview devices: TPS543C20

Learn more: New advanced current-mode control topology—The basics

Hysteretic Control Mode

The simplest control scheme. The PWM (SW) on-time (T_{ON}) is terminated when the feedback voltage is greater than a reference-high threshold and the off-time (T_{OFF}) is terminated when the feedback voltage is less than a reference-low threshold. No compensation components are required. The PWM switching frequency is not controlled and varies with load current and delivers higher efficiency at lighter loads.



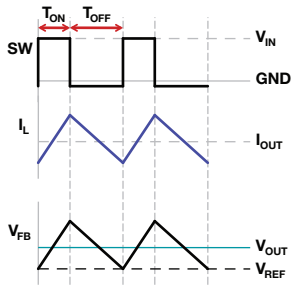
When to use: When fast transient response is required. There is no clock-signal time delay to initiate the ramp. A certain amount of ripple is required at the output from the output capacitor's ESR.

Popular devices: LM3475, LM3485

Learn more: LM3485 Datasheet (SNVS178H)

Constant On-Time (COT)

A slight variation to hysteretic control minimizing frequency shift, but with a single voltage-threshold level, yet achieving fast transient response. The on-time is terminated by a one-shot on-timer and is proportional to the input voltage. The off-time is terminated when the feedback voltage falls below the reference-low threshold.



When to use: When fast transient response is required and a fixed or predictable switching frequency is not required. A certain amount of ripple is required at the output from the output capacitor ESR.

Popular devices: LM5017, LM2696, TPS54A20

Learn more: Controlling Output Ripple and Achieving ESR Independence in Constant On-Time (COT) Regulator Designs (SNVA166A)

Constant On-Time with Emulated Ripple Mode (COT with ERM)

A variation of the COT regulator that senses a portion of the low-side MOSFET's off-time current and injects it into the error comparator to emulate ripple. This control mode has the same fast transient response and fewer external component advantages of COT.

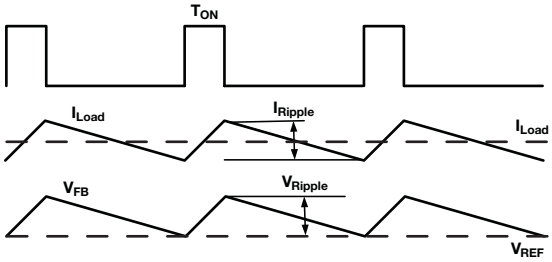
When to use: When employing low-ESR ceramic capacitors or when an external ripple injection circuit is undesirable.

Popular devices: LM3100, LM3150

Learn more: Emulated ripple technique advances hysteretic switchmode supplies, EE Times

D-CAP™ (Direct Connection to the Output Capacitor)

Similar to COT control except a one-shot timer generates an on-time pulse that is proportional to the input voltage and the output voltage. When the falling feedback voltage equals the reference voltage, a new PWM on-pulse is generated. Fast response to load changes is achieved with a high-speed comparator in the control loop. D-CAP™ minimizes frequency shift compared to hysteretic control.



When to use: When a fast transient response is required and POSCAP or medium-ESR output capacitors are used. No loop-compensation calculation or components are needed.

Popular devices: TPS51116, TPS53219A, TPS53355

Learn more: Adaptive Constant On-Time (D-CAP™) Control Study in Notebook Applications (SLVA281A)

D-CAP2™

A slight variation of D-CAP with the same transient and external component advantages as D-CAP. This control mode supports ceramic output capacitance without external circuitry. A signal from an internal ripple-injection circuit is fed directly into the comparator, thus reducing the need for output voltage ripple from the capacitor's ESR. The ramp is emulated by the output inductor.

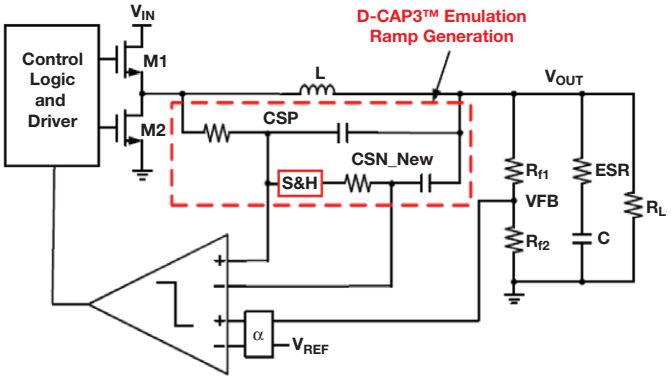
When to use: When desiring fast transient response with low-ESR ceramic output capacitors.

Popular devices: TPS53014, TPS54325, TPS563210

Learn more: D-CAP2™ Frequency Response Model based on frequency domain analysis of Fixed On-Time with Bottom Detection having Ripple Injection (SLVA546)

D-CAP3™

A variation of D-CAP2™ with the same transient and external component advantages. A sample-and-hold circuit is built-in to the converter to remove an offset voltage created by D-CAP2's emulated ramp circuit, improving the voltage reference accuracy. Well suited for powering low-core-voltage FPGAs, ASICs and DSPs.



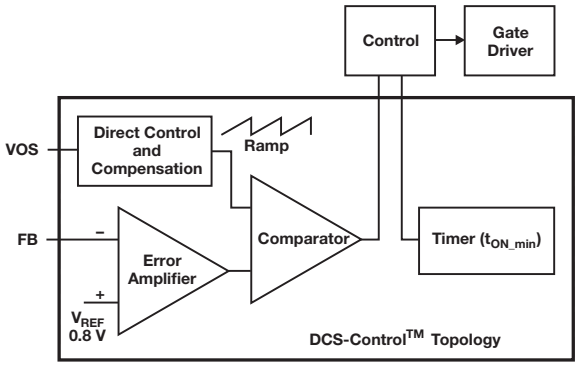
When to use: When a tighter reference voltage accuracy and a fast transient response are desirable when using ceramic output capacitors.

Popular devices: TPS56C215, TPS548A20, TPS548D22

Learn more: Accuracy-Enhanced Ramp-Generation Design for D-CAP3 Modulation (SLVA762A)

DCS-Control™: Direct Control with Seamless Transition into Power-Save Mode

Combines the advantages of hysteretic control for a fast transient response without compensation components, and the advantages of voltage-mode control for high DC accuracy with a seamless transition from PWM to power-saving mode (PSM).



When to use: When light-load efficiency is needed with small, low-ESR ceramic capacitors.

Popular devices: TPS62130, TPS62097, TPS82130

Learn more: High-efficiency, low-ripple DCS-Control™ offers seamless PWM/power-save transitions (SLYT531)

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