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.

<table>
<thead>
<tr>
<th>Voltage Mode (VM)</th>
<th>Voltage Mode with Feedforward (VFF)</th>
<th>Peak Current Mode</th>
<th>Emulated Current Mode (ECM)</th>
<th>Internally-Compensated Advanced Current Mode (ACM)</th>
<th>Hysteresis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant On Time (COT)</td>
<td>COT with Emulated Ripple (COT with ERM)</td>
<td>D-CAP™</td>
<td>D-CAP2™</td>
<td>D-CAP3™</td>
<td>OSC Control™</td>
</tr>
</tbody>
</table>

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, TPS64478, LM5140-Q1

Learn more: Understanding and Applying Current-Mode Control Theory (SNA555)
**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.

**Popular devices:** TPS543C20, TPS543B20

**Learn more:** Internally Compensated Advanced Current Mode (ACM) (SLYY115)

**Hysteretic Control Mode**

The simplest control scheme. The PWM (SW) on-time (TON) is terminated when the feedback voltage is greater than a reference-high threshold and the off-time (TOFF) 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, LM2699, 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 (SLVA62A), Comparing Bode plots in D-CAP3™ control mode

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: TPS52130, TPS62097, TPS82130

Learn more: High-efficiency, low-ripple DCS-Control™ offers seamless PWM/power-save transitions (SLYT53)
TI Support
Thank you for your business. Find the answer to your support need or get in touch with our support center at

www.ti.com/support

China: http://www.ti.com.cn/guidedsupport/cn/docs/supporthome.tsp
Japan: http://www.tij.co.jp/guidedsupport/jp/docs/supporthome.tsp

Technical support forums
Search through millions of technical questions and answers at TI's E2E™ Community (engineer-to-engineer) at
e2e.ti.com

China: http://www.deyisupport.com/
Japan: http://e2e.ti.com/group/jp/

TI Training
From technology fundamentals to advanced implementation, we offer on-demand and live training to help bring your next-generation designs to life. Get started now at

training.ti.com

Japan: https://training.ti.com/jp

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

The platform bar, D-CAP, D-CAP2, D-CAP3, DCS-Control and E2E are trademarks of Texas Instruments. All other trademarks are the property of their respective owners.
IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI') technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include, without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated