*Application Note*

# *Transient Response Comparison of AECM with D-CAP2 and PCM Control*

*Harry Ma, Zhao Young*

**ABSTRACT**

The output voltage transient of a buck regulator during a load current step is often a key performance specification, which is the response characteristic to a sudden load fluctuation, that is, the time until the output voltage returns to a preset value after having fallen or risen, and the waveform of the output voltage. While there are many types of control topologies addressing special design challenges for non-isolated DC/DC converter, including peak current mode control, constant on-time (COT) control, D-CAP2™ control mode (a variation of adaptive constant-on time control mode), advanced emulated current mode (AECM). The various control modes each has unique advantages. This note, we will provide a performance comparison of DC/DC converters operating in three different modes: PCM control mode, D-CAP2™ control mode (a derivative of constant on-time), and AECM control mode. These three control modes were all used widespread, none of these control modes require loop compensation which making the design simple.

## Table of Contents



## List of Figures



## List of Tables



## Trademarks

D-CAP2™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

# 1 Introduction

The output voltage transient of a buck regulator during a load current step is often a key performance specification.While there are many types of control topologies addressing special design challenges for non-isolated DC/DC converter, including Voltage-mode control, peak current mode control, constant on-time (COT) control, D-CAP2 control mode a variation of adaptive constant-on time control mode, advanced emulated current mode (AECM).

No single control topology is a good fit for all applications. The various control modes each has unique advantages. This note, we will provide a performance comparison of DC/DC converters operating in three different modes: PCM control mode, D-CAP2™ control mode (a derivative of constant on-time), and AECM control mode. These three control modes were all used widespread, none of these control modes require loop compensation which making the design simple.

## 1.1 PCM

PCM is a popular fixed-frequency control topology for DC/DC converters given its overload protection, accuracy and ease of compensation. The power stage consists of the power switches and output filter. The compensation block includes the output voltage divider network, error amplifier, reference voltage and compensation components. The pulse-width modulator uses a comparator to compare the inductor current information with the slope compensation ramp to the error signal, creating an output pulse-train that has a width controllable by the level of the error signal.

The internal clock initiates one pulse, and the high-side field-effect transistor (FET) turns on, with current increasing in the inductor. When the sensed current reaches the control voltage, the high-side FET turns off and the low-side FET turns on until the next rising edge of the clock. The next PWM pulse is generated at the next clock pulse. Thus, the switching frequency depending on the clock is truly fixed. which is convenient when designing the output filter for low electromagnetic interference (EMI).

## 1.2 DCAP2

The D-CAP2 control mode is a variation of adaptive COT control mode which is popular in buck converters because of its simplicity and improved load-transient performance. There is an emulated ramp-generator circuit integrated inside the IC with D-CAP2 control mode. The ramp generator (ripple injection generator) emulates the inductor current information and brings this information back to the comparator. When the emulated ramp voltage and feedback voltage are lower than the reference voltage, the comparator output goes high to initiate an on-time pulse. The width of the on-time pulse (Ton) is constant, since it is calculated by the adaptive on-time generator based on the input voltage, output voltage, output current and frequency setting. The off-time relies on the voltage ripple, which has some variation during a line or load transient. As a result, the switching frequency is pseudo-fixed.

## 1.3 AECM

AECM is a topology based on a fixed frequency modulator with emulated current information for the loop control. It combines the fixed frequency of PCM control and the fast load-transient response of the D-CAP control topology. The integrated oscillator generates the fixed clocks, and the emulated ramp generator with the smart loop-bandwidth control circuit can adjust the DC gain to achieve high bandwidth overall output rails. And even though there is an integrator, unlike PCM control, the integrator in AECM control can improve output-voltage accuracy with no direct impact on loop response speed. More details about AECM are in *Achieving Fast Load-Transient Response and Low EMI with the AECM DC/DC Control Topology*

# 2 Transient Response Comparison

Three power supplies were chosen to demonstrate the performance of each control mode under the same operating conditions:

- PCM buck converter Part1 switching at 600 kHz
- D-CAP2 buck converter Part2 switching at 580 kHZ
- AECM buck converter TPS563211 switching at 600 kHz

Operating frequencies were selected as close as possible, allowing every design to use the same output filter.

Table 2-1 shows all device configurations. The inductor chosen for all designs is the Wurth 74437349033, which is a 6-A, 0.019-mΩ, 3.3 uH coil. Output cap are composed by 2 × 22 uF TDK C3216X5R1V226M160AC, and 0.1 u Kemet C0603C104K5RACAUTO.

**Table 2-1. Converter and Setup Summary**

| Part Number | Control Mode | Fsw | Inductor | Output Capacitance |
|---|---|---|---|---|
| Part1 | PCM | 600 kHz | 3.3 uH | 44 uF+ 0.1 uF |
| Part2 | DCAP2 | 580 kHz | 3.3 uH | 44 uF + 0.1 uF |
| TPS563211 | AECM | 600 kHz | 3.3 uH | 44 uF + 0.1 uF |

The D-CAP2 control mode is nonlinear, its Bode plot is difficult to measure because the feedback loop is not fully disconnected internally. We use load transient to represents the dynamic performance. We performed load-transient test with a 0 A to 3 A, 0.3 A to 2.7 A, 1.5 A to 3 A load step with slew rate of load is 2.5 A/µs. Figure 2-1 to Figure 2-9 show the transient response difference of PCM, DCAP2, and AECM parts.

Comparing the transient response waveforms shown as below of three control modes. AECM and D-CAP2 with an emulated ramp-generator circuit integrated inside IC have an advantage over the PCM solution, with a smaller voltage overshoots and undershoots. Table 2-2 shows the results.

**Table 2-2. Transient Response Summary**

| Part | Output Voltage Peak-Peak | | |
|---|---|---|---|
| | Transient(0A-3A) | Transient(0.3 A-2.7 A) | Transient(1.5 A-3 A) |
| Part1 | 520 mv | 408 mv | 264 mv |
| Part2 | 268 mv | 280 mv | 196 mv |
| TPS563211 | 220 mv | 220 mv | 160 mv |

The following images are the application curves.

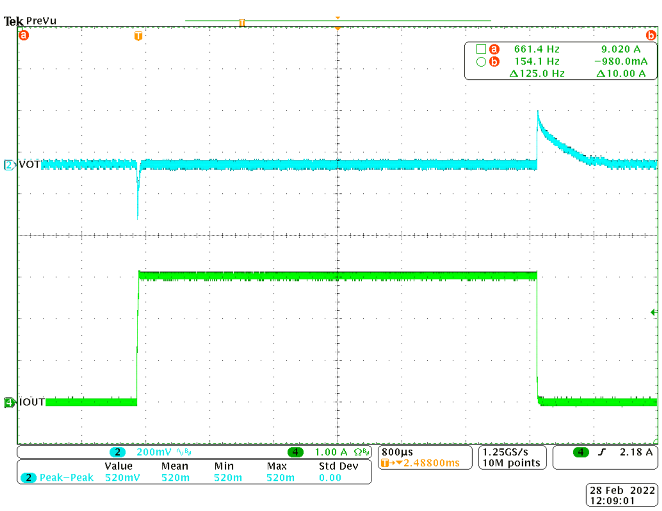


**Figure 2-1. Part1 PCM Transient Response 0A-3 A**

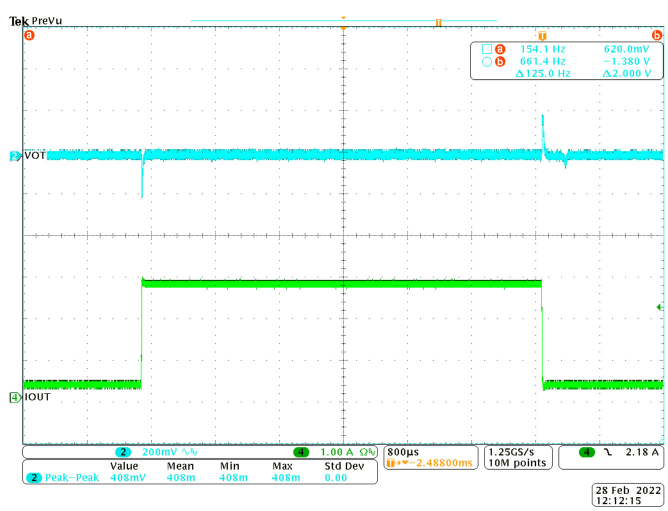


**Figure 2-2. Part1 PCM Transient Response 0.3A-2.7 A**

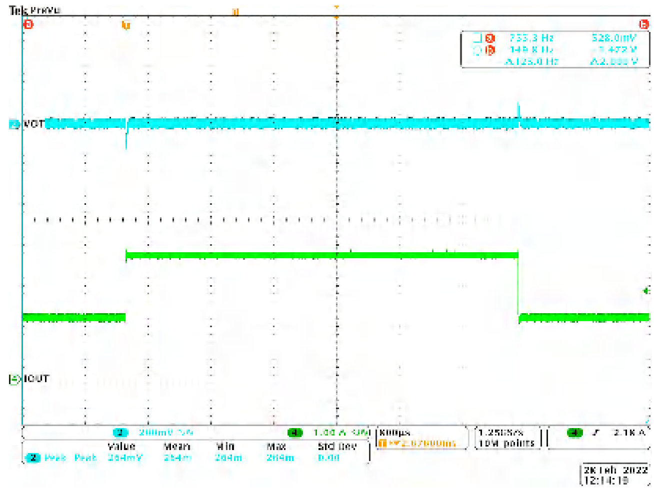


Figure 2-3. Part1 PCM Transient Response 1.5A-3A

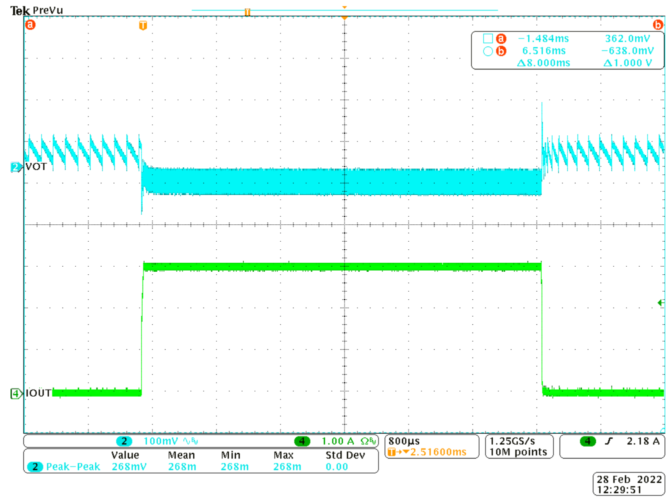


Figure 2-4. Part2 DCAP2 Transient Response 0A-3A

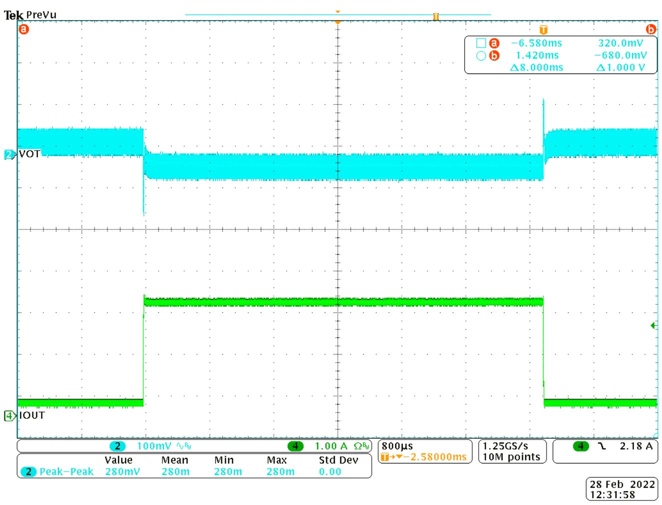


Figure 2-5. Part2 DCAP2 Transient Response 0.3A-2.7A

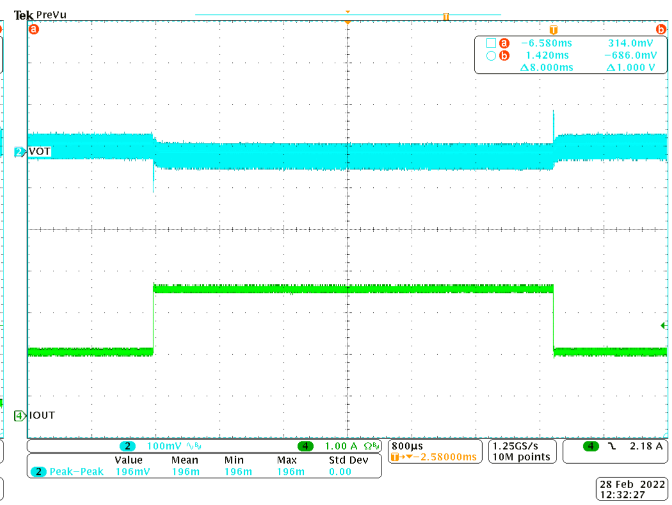


Figure 2-6. Part2 DCAP2 Transient Response 1.5A-3A

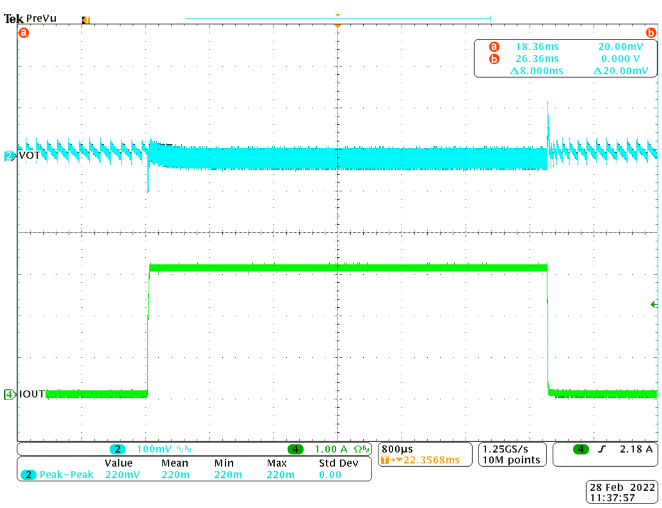


Figure 2-7. TPS563211 AECM Transient Response 0A-3A

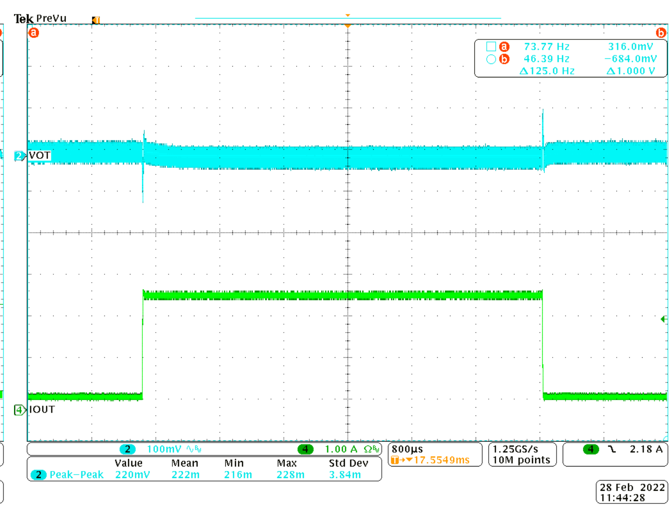


Figure 2-8. TPS563211 AECM Transient Response 0.3A-2.7A

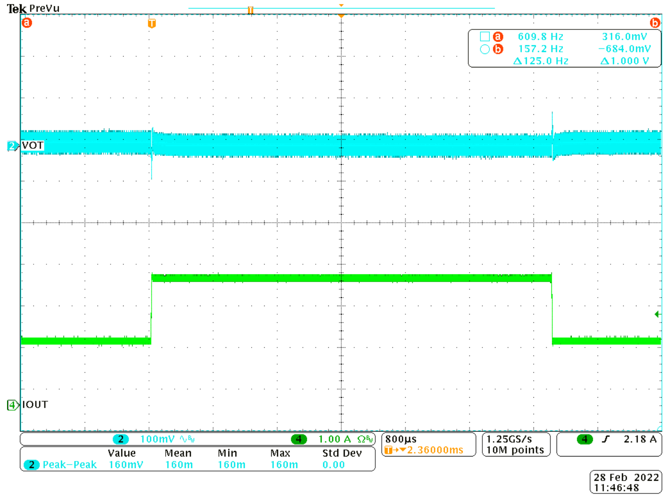


**Figure 2-9. TPS563211 AECM Transient Response 1.5A-3A**

Figure 2-10 to Figure 2-12 show the switch-node waveform of three control modes during a transient load step. We can see the PCM and AECM has a fixed frequency during load transient when working at CCM, and it's easy to deal with EMI. And for D-CAP2 control topology, the off-time will be adjusted to respond the load transient, so the switching frequency is pseudo-fixed.

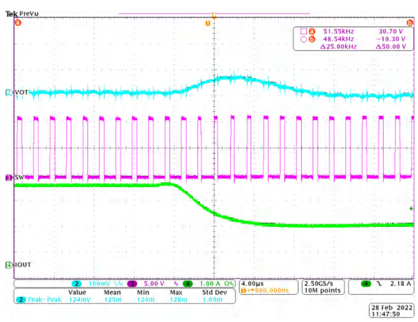

**Figure 2-10. AECM Transient Response 1.5 A-3 A (Zoom in)**

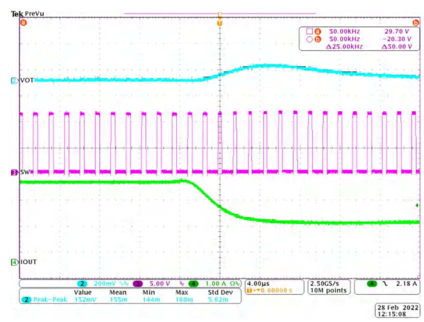

**Figure 2-11. PCM Transient Response 1.5 A-3 A (Zoom in)**

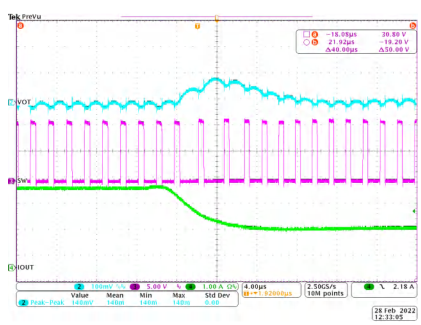

**Figure 2-12. DCAP2 Transient Response 1.5 A-3 A (Zoom in)**

## 3 Summary

There is no perfect control mode for every situation. When designing a wireless access point or a remote radio unit using data converters and other noise-sensitive circuitry, a fixed, predictable switching frequency that is synchronizable to an external clock can be the preferred design. On the other hand, many designers are looking for easy-to-use DC/DC converters that do not require tedious compensation calculations. They may also wish to reduce the required output capacitance to meet the processor's demanding load transient and voltage-tolerance requirements. Table 3-1 summarizes the comparison between three control modes.

**Table 3-1. Comparison of Different Modes**

| Control Mode | Transient Response | Fixed Frequency |
|---|---|---|
| PCM | Medium | Yes |
| D-CAP2 | Fast | No |
| AECM | Fast | Yes |

All control modes complement others and has its own merit. Devices with the AECM control topology for DC/DC converters can achieve a fast load-transient response with a true fixed frequency, while still maintaining a wide output voltage and low design cost. This new control topology has been implemented in several products with good performance, ease of use and small solution size.

# 4 References


- Texas Instruments, *TPS563211 4.2-V to 18-V Input, 3-A Synchronous Buck Convertor in SOT583*, data sheet.
- Texas Instruments, *Achieving Fast Load-Transient Response and Low EMI with the AECM DC/DC Control Topology*.
- Texas Instruments, *TPS563211EVM Evaluation Module User's Guide*.

## IMPORTANT NOTICE AND DISCLAIMER