Fixed-frequency DCS-Control: Fast transient response with clock synchronization

Chris Glaser
Senior Member, Technical Staff

Introduction

A common drawback with constant on-time (COT) control topologies is the switching frequency variation and inability to synchronize to an external clock. TI's fixed-frequency direct control with seamless transition into power save mode (fixed-frequency DCS-Control) topology builds on the popular COT DCS-Control topology with its fast transient response, and adds an oscillator to achieve fixed-frequency operation with optional clock synchronization. This combination enables applications that require both a fast transient response and have specific noise or frequency requirements.

Other features such as differential remote sensing, external control-loop compensation and stackability support the demanding transient requirements of higher-current processors found in noise-sensitive applications, including automotive infotainment and advanced driver assistance systems (ADAS), communications equipment optical modules, industrial test and measurement, medical, and aerospace and defense. This article provides an overview of the fixed-frequency DCS-Control topology, discussing its excellent transient response, constant and synchronize-able switching frequency, lower-ripple power-save mode, and stackability for higher currents.

DCS-Control topology overview

Figure 1 shows the basic block diagram of the DCS-Control topology [1]. Both the output-voltage sense (VOS) and feedback (FB) pins provide the inputs to the control loop for proper regulation. The VOS pin provides the topology's fast transient response by directly feeding the output voltage into a ramp and then into the comparator, where it immediately affects the operating point. The FB pin is a lower-bandwidth path that provides highly accurate DC setpoint regulation. When combined in DCS-Control, the VOS pin's AC path and FB pin's DC path provide an accurate output voltage that also responds quickly to load transients.

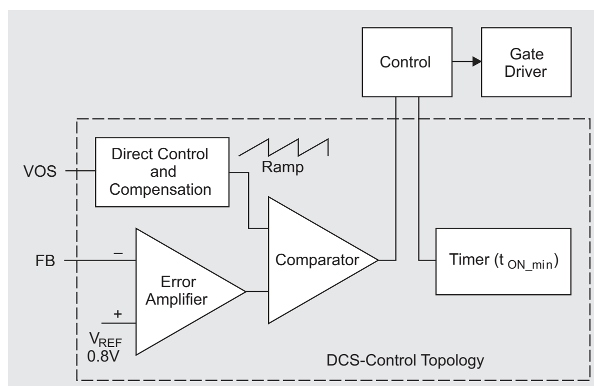

Figure 1. *Block diagram of the DCS-Control topology.*

A COT topology such as DCS-Control sets the on-time with a timer. By adjusting this on-time with the input and output voltage, the timer gives a reasonably constant frequency operation for most duty cycles in pulse-width modulation (PWM) mode. Equation 1 shows an example, where 416ns is the period for a 2.4MHz switching frequency:

$$t_{ON} = \frac{V_{OUT}}{V_{IN}} \times 416ns \quad (1)$$

However, the switching frequency is not precise enough for applications that require operation inside or outside of a specific frequency band. These applications generally require setting the switching frequency with an oscillator, such as in voltage- or current-mode control, and in some cases, the ability to synchronize with a system clock signal. Reference [2] offers further examples of the frequency variation of DCS-Control.

Fixed-frequency DCS-Control topology overview

Figure 2 shows a basic block diagram of the fixed-frequency DCS-Control topology, as implemented in the 15A **TPS62873** buck converter. The addition of an oscillator enables the direct setting of the switching frequency (f_{SW}) in the same way as voltage- or current-mode control. Having an oscillator input into the control loop also provides the ability to synchronize the switching frequency to an applied clock signal.

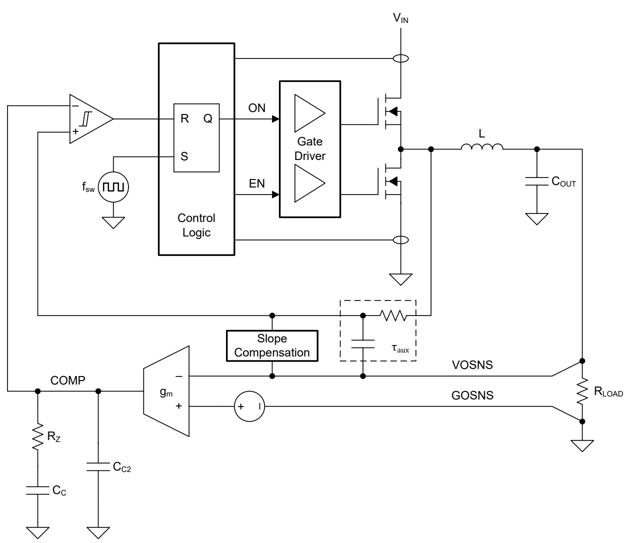

Figure 2. *Block diagram of the TPS62873's fixed-frequency DCS-Control topology with the oscillator, differential remote sensing, transconductance amplifier and hysteretic comparator.*

Fixed-frequency DCS-Control, usually used in higher-current devices, uses differential remote sensing. The device regulates the voltage between the VOSNS and GOSNS pins, which are routed across the printed circuit board (PCB) to sense the output voltage directly at the load. Sensing at the load overcomes and compensates for not only the DC voltage drops across the PCB planes and traces, but also the delays that come from inductance between the device and the load. Both of these characteristics are important for maintaining very tight regulation across the load range and during load transients.

The differential remote-sensing signals are fed into the transconductance amplifier (g_m), which compares their difference against the output voltage setpoint. (For simplicity, **Figure 2** shows this setpoint as a voltage source in series with the GOSNS signal.) The COMP pin gives the output of this amplifier, which is compensated with a Type II (one pole, one zero) network to ground.

This external compensation allows you to optimize the control loop to any system need – from systems with strong load transients with large output capacitance, all the way down to systems with small or no load transients with very little output capacitance and small size. Unlike DCS-Control, the fast feedback path goes through this amplifier – not immediately to the comparator – where compensation component selection can increase (or decrease) the gain. If you need a stronger transient response, you increase the gain and add more output capacitance. If no strong transients are present in the application, you decrease the gain and use a minimal amount of output capacitance in order to achieve the smallest size.

The ability to adjust the transient response to the application needs enables tighter regulation under harsher transients than what is possible with the previous DCS-Control topology, and meets the requirements of demanding processor cores such as TI's Jacinto™ J7 and MobileEye's EyeQ6 [3-4]. **Figure 3** shows a stack of three **TPS62876-Q1** buck converters delivering a 46A load transient, while maintaining the output voltage within ±2% of the 0.875V setpoint.

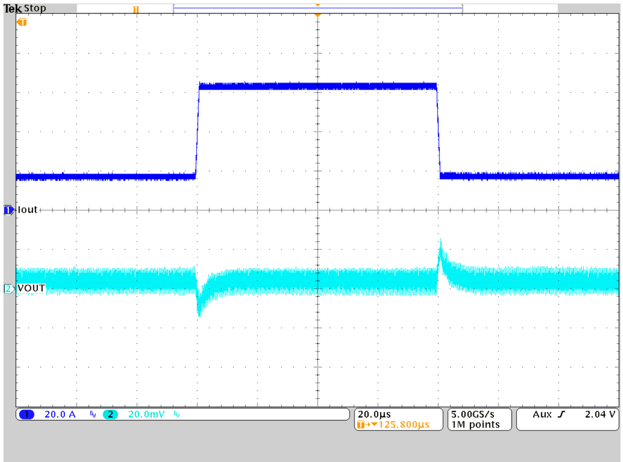

***Figure 3.** The transient response of fixed-frequency DCS-Control is tunable to the most severe load transients, where it provides excellent regulation.*

A hysteretic comparator compares the COMP pin output and a replica of the inductor current, created by the τ_{aux} components, with slope compensation added to prevent subharmonic oscillations. The comparator's output drives the Set-Reset (SR) latch circuitry, along with the clock, which controls the gate drivers and device operation. The oscillator controls the switching to occur exactly at the switching frequency.

The Set-Reset latch is a simplified representation of the detailed operation of the control block and is implemented to maintain the fast, hysteretic nature of DCS-Control and thus enable an immediate response to load transients. For example, during a load-dump transient (where the output voltage rises), the output of the hysteretic comparator has priority over the clock signal. The converter extends the off-time of the high-side MOSFET as needed to bring the output voltage back down with minimum overshoot. This is inherently improved behavior compared to textbook peak current-mode control, which switches at every clock cycle, continuing to add energy to the output, even while it is too high. By reducing the output-voltage overshoot, the converter significantly reduces the output capacitance, which is a key influence on the cost and size of the power supply.

Switching frequency variation

In addition to maintaining the fast transient response, which can be further improved and tuned through the external compensation on the COMP pin, fixed-frequency DCS-Control provides a fixed switching frequency with a tight tolerance specification. Because the switching frequency is directly set with an oscillator instead of indirectly controlled with an on-timer, the frequency's tolerance is specified in the device-specific data sheet. Table 1 and Table 2 compare the switching frequency specifications of the TPS62876-Q1, using the fixed-frequency DCS-Control topology, versus the typical frequency specification of the DCS-Control TPS62869 step-down converter.

Parameter		Test Conditions	MIN	TYP	MAX	Unit
f_{SW}	Switching Frequency	f_{SW} = 1.5MHz, PWM operation	1.35	1.5	1.65	MHz
		f_{SW} = 2.25MHz, PWM operation	2.025	2.25	2.475	
		f_{SW} = 2.5MHz, PWM operation	2.25	2.5	2.75	
		f_{SW} = 3MHz, PWM operation	2.7	3	3.3	

***Table 1.** The TPS62876-Q1, using the fixed-frequency DCS-Control topology, specifies a ±10% tolerance of its four switching frequency options over the full temperature and input voltage ranges.*

Parameter		Test Conditions	MIN	TYP	MAX	Unit
f_{SW}	PWM switching frequency	I_{OUT} = 1A, V_{OUT} = 0.9V		2.4		MHz

***Table 2.** The TPS62869, using DCS-Control, only specifies a typical switching frequency.*

Figure 4 and Figure 5 compare the actual variation of the switching frequency versus load current in an application. Both devices support power-save mode, which reduces the frequency at lower load currents (toward the left of both graphs). Operation in PWM mode (at higher currents) results in a precisely controlled switching frequency for fixed-frequency DCS-Control, while the switching frequency of DCS-Control increases slightly with an increasing load. In forced PWM mode (not shown), fixed-frequency DCS-Control maintains its constant frequency down to no load.

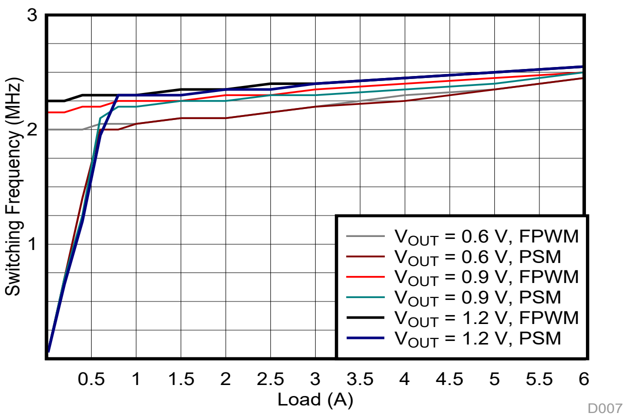

Figure 4. *Switching frequency variation of the TPS62869 with DCS-Control.*

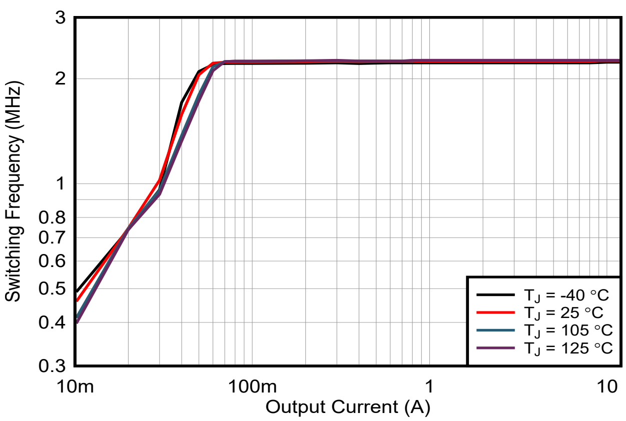

Figure 5. *Switching frequency variation of the TPSM8287A12 power module with fixed-frequency DCS-Control.*

Besides power-save mode, there are two conditions where the switching frequency can deviate from the frequency set by the oscillator: during a strong load transient and if the minimum on-time is reached. When applying a heavy load, the high-side MOSFET may be on for longer than a full switching period, and when removing a heavy load, it may be off for longer than a full switching period. Both scenarios result in one or more pulses that are not present because of the extended on- or off-times.

If the minimum on-time of the high-side MOSFET is reached, both fixed-frequency DCS-Control and DCS-Control reduce the switching frequency in order to meet the minimum on-time and maintain output-voltage regulation. This is improved performance compared to some current-mode devices that maintain the frequency but let the output voltage rise in order to meet the required minimum on-time. While both fixed-frequency DCS-Control and DCS-Control reduce the switching frequency in the same way [2], fixed-frequency DCS-Control has fewer operating conditions during which the minimum on-time is reached, and the frequency reduced, because of its lower minimum on-time. For example, the **TPS62876-Q1** specifies the 44ns maximum value of its minimum on-time at a 5V input voltage and across the operating temperature. Such a low value of minimum on-time enables lower output-voltage applications in automotive and aerospace and defense, for example, to operate in the higher-frequency region sometimes required by the overall system.

Lower-ripple power-save mode

While most applications operate a fixed-frequency DCS-Control device in forced PWM mode in order to obtain lower output-voltage ripple at light loads and a better transient response, the topology does support a power-save mode to increase efficiency at light loads. To maintain the target switching frequency and provide lower ripple down to lower load currents, fixed-frequency DCS-Control reduces the on-time in power-save mode, whereas DCS-Control keeps the on-time constant. Both topologies enter power-save mode when the inductor current becomes discontinuous, which creates slightly higher ripple compared to PWM mode.

Instead of reducing the frequency with the same on-time, fixed-frequency DCS-Control's power-save mode reduces the on-time while maintaining the same frequency. Reducing the on-time delivers less energy to the output, thereby reducing the ripple voltage compared to DCS-Control. Once the on-time reduces to its minimum, skipping pulses reduces the output power further for the lightest loads. Skipping pulses also reduces the frequency.

Figure 4 and **Figure 5** show the difference in frequency reduction in power-save mode. The fixed-frequency DCS-Control device reduces its frequency below loads of around 60mA, while the DCS-Control device begins reducing the frequency around 500mA. Although these current values are different for different devices and operating conditions, fixed-frequency DCS-Control maintains its switching frequency down to lower load currents, leading to lower ripple.

Stacking (paralleling) for higher (or lower) load currents

On one hand, processor cores frequently require higher currents with each successive processor generation. On the other hand, some applications may not use all of the functionality of a given processor or may use a less-capable processor within the same processor family, resulting in lower current requirements. Scaling the power supply's current capability both up and down requires a stackable (parallelable) solution where it is possible to add or remove additional power-supply phases as the current requirements change.

Fixed-frequency DCS-Control devices support stacking. While the specific implementation details vary slightly between each device family, features include current sharing, phase interleaving and interface simplicity.

Current sharing is accomplished through the COMP pin. Since the COMP pin is essentially the small-signal operating point, sharing this pin's signal between all stacked devices enables fixed-frequency DCS-Control to typically achieve tighter than 10% current-sharing accuracy.

Phase interleaving is accomplished by a dedicated SYNC_OUT pin, which connects to the MODE/SYNC input pin of the next device in the stack. SYNC_OUT is automatically phase-shifted in order to provide ripple cancellation. Through this simple daisy chaining, all devices in the stack operate at the same frequency and with lower ripple than a single-phase design. You can stack a large number of converters and achieve very good phase balancing without needing to specify the number of devices in the stack.

When interfacing to the stack through I2C, communication only happens to the primary device – not each device in the stack – in order to adjust the output voltage, change the operating mode, or read back fault registers. Interfacing to a single device greatly simplifies the communication overhead and PCB routing by both reducing the number of reads and writes and the number of PCB signals that need routing.

Conclusion

With its fast transient response and stackability, fixed-frequency DCS-Control powers the latest processors' demanding load transient and output-current requirements, while its fixed-frequency operation and synchronization make it a great fit for noise-sensitive applications. Automotive ADAS and infotainment, optical modules, industrial test and measurement, medical, and aerospace and defense applications all benefit. The tunable external control-loop compensation supports a fast transient response with the minimum amount of output capacitance, reducing the size and cost of a power-supply system.

References

1. Texas Instruments: ***High-efficiency, low-ripple DCS-Control offers seamless PWM/power-save transitions***
2. Texas Instruments: ***Understanding frequency variation in the DCS-Control topology***
3. Texas Instruments: ***Powering Jacinto J7 SoC Family for Isolated Power Groups with TPS6594133A-Q1 PMIC and Dual HCPS Converters***
4. Texas Instruments: ***MobileyeEyeQ6L – Semi Discrete Power Tree***
5. Priess, Canan."**How to Deliver Current Beyond 100 A to an ADAS Processor**." TI E2E™ design support forums technical article, June 6, 2023.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265