CURRENT MODE OR VOLTAGE MODE ?

by Dr. Ray Ridley

Current-mode control was formally introduced to the power electronics world in 1978 [1]. It was quickly accepted as the most rugged way to control power supplies. Recently, however, some companies reverted back to voltage-mode control when complications arose in implementing current-mode control. In this article, we'll consider the advantages and disadvantages of each type of control scheme.

In voltage-mode control, an error voltage is compared to a sawtooth ramp to control the duty cycle of the power switch. The higher the error voltage, the longer the switch is on. And the error voltage is derived in the feedback system from the error amplifier that amplifies the difference between the output voltage and the reference voltage. *Figure 1* shows the basic circuit for a point-of-load converter (the same circuit used in the July 2000 issue of ***Switching Power Magazine*** for the two-stage filter design.) The control-to-output transfer function for the buck converter looks like a typical filter characteristic:

$$\frac{v_o}{v_c} = K_v \frac{1 + sCR_c}{1 + \frac{s}{\omega_o Q_p} + \frac{s^2}{\omega_o^2}} \quad \text{where} \quad \omega_o = \frac{1}{\sqrt{LC}}$$

Current-mode control is shown in *Figure 2*. The error voltage is used to directly control the peak of the switch current. (A sawtooth ramp is still used in some cases and is referred to in current-mode as a compensating ramp.) This dramatically changes the behavior of the system. For the buck converter, the control-to-output transfer function with current-mode control becomes:

$$\frac{v_o}{v_c} = K_i \frac{1 + sCR_c}{1 + sCR_L} F_h(s)$$

where $F_h(s)$ is a second-order pair of poles at half the switching frequency [2].

The major advantages and disadvantages of current-mode are summarized in the tables.

Current-Mode Control *Advantages*

#1: Easy Compensation

With voltage-mode, the sharp phase drop after the filter resonant frequency requires a type three compensator to stabilize the system. Current-mode control looks like a single-pole system at low frequencies, since the inductor has been controlled by the current loop. This improves the phase margin, and makes the converter much easier to control. A type two compensator is adequate, which greatly simplifies the design process. *Figure 3* compares the power stage gain and phase of voltage-mode and current-mode, showing how much easier the current-mode system is to compensate.

#2: RHP Zero Converters

Contrary to some papers on the topic, current-mode control does NOT eliminate the right-half plane (RHP) zero of boost, flyback, and other converters. It does make compensation of such converters easier, though. With voltage-mode control, crossover has to be well above the resonant frequency, or the filter will ring. In a converter where the crossover frequency is restricted by the presence of an RHP zero, this could be impossible. It's not a problem with current-mode control to have a control loop crossover at or below the filter resonant frequency.

#3: CCM and DCM Operation

When moving from continuous-conduction mode (CCM) to discontinuous-conduction mode (DCM), the characteristics with voltage-mode control are drastically different as shown in *Figure 4*. It is not possible to design a compensator with voltage-mode that can provide good performance in both regions. With current-mode, crossing the boundary between the two types of operation is not a problem. The characteristics are almost constant in the region of crossover, as shown in *Figure 5*. Having optimal response in both modes is a major advantage, allowing the power stage to operate much more efficiently. Keeping a converter in DCM for all changes of load, line, temperature, transients, and other parameter variations can lead to severe component stresses.

#4: Line Rejection

Closing the current loop gives a lot of attenuation of input noise. For the buck, it can even be nulled under some special conditions, with the proper compensating sawtooth ramp. Even with only a moderate gain in the voltage feedback loop, the attenuation of input ripple is usually adequate with current-mode control. With voltage-mode control, far more gain is needed in the main feedback loop to achieve the same performance.

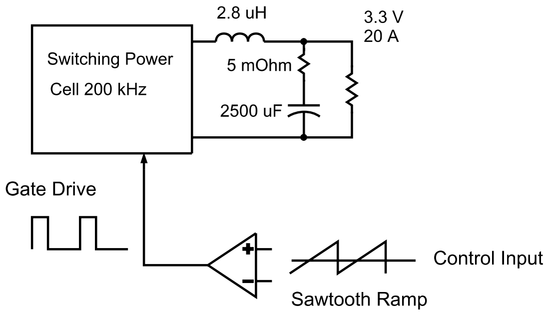

Fig. 1: Point-of-Load Buck Converter with Voltage-Mode Control

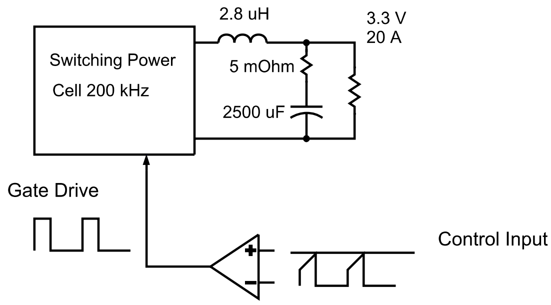

Fig. 2: Point-of-Load Buck Converter with Current-Mode Control

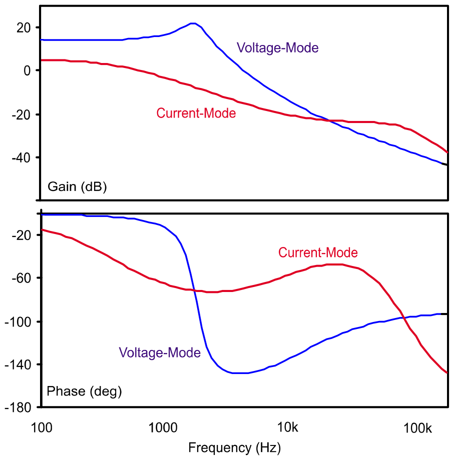

Fig. 3: Voltage-Mode/Current-Mode Comparison

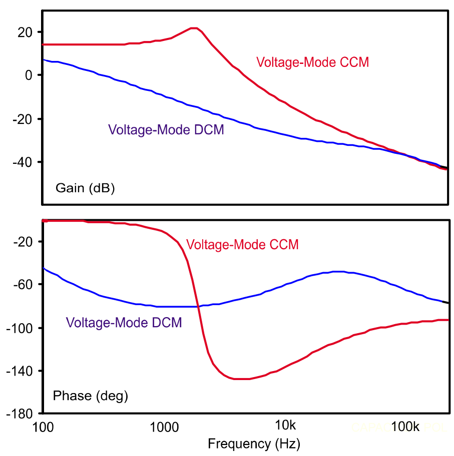

Fig. 4: Voltage-Mode Control in CCM and DCM

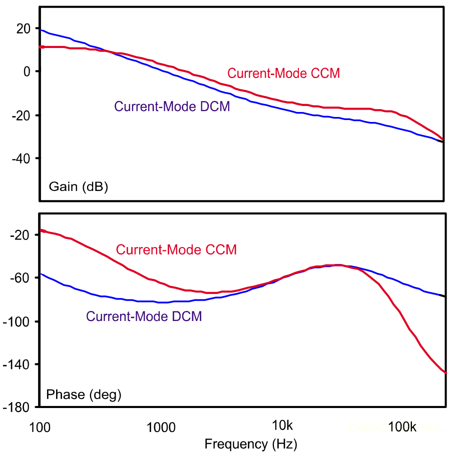

Fig. 5: Current-Mode Control in CCM and DCM

Current-Mode Control *Disadvantages*

#1: Current Sensing

Either the switch current or inductor current must be sensed accurately. This requires additional circuitry, and some power loss. In most isolated power supplies, the switch current is sensed either with a resistor or current transformer. The current sensing must be very wideband to accurately reconstruct the current signal. A current transformer needs a bandwidth several orders of magnitude above the switching frequency to work dependably.

#2: Subharmonic Oscillations Instability

Current-mode control can be unstable when the duty cycle of the converter approaches 50%. This does not occur abruptly at 50%, as some data books claim, but can manifest the problem even at lower duty cycles. A compensating ramp is needed to fix the problem, and this too can introduce complications. See [2] for further information.

#3: Signal-to-Noise Ratio

The biggest problem in almost every current-mode supply is noise on the current sense signal. In many power supplies there is simply not enough signal to control the converter smoothly over the full range of operation.

Even with the ideal current waveform of Figure 6a, the signal available for control is small. The peak of the current signal is limited by the PWM controller, usually to less than 1 V. Much of the available signal range can be taken by the DC value of the switch current. When the real current waveform of Figure 6b, with spikes and ringing is considered, the problem becomes even worse.

Solutions include filtering, sensing the current waveform at different places (e.g., the output side of a buck inductor), and leading-edge blanking, where the initial part of the signal with the most noise is ignored. Even with these approaches, which all carry their own complications, current-mode can be unworkable.

Many IC manufacturers have attempted to place all the power supply functions on a single chip, including the current sensing and filtering. In these cases, they have often found the current-mode noise problems insurmountable and have converted to voltage-mode control. Unfortunately, with voltage mode, all the inherent advantages of current mode are lost.

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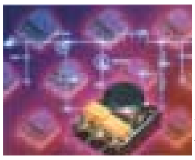
Industry News

New from **International Rectifier**:

Automotive Power Integrated Circuit Designer's Manual. Automotive electrical and electronic control systems designers searching for fully-protected power MOSFET switches and special function ICs will find this 397-page reference source very handy.



Omnirel, an International Rectifier company, introduced four *high-efficiency, low-voltage switching regulators* in plastic packages that economically increase power density in select commercial, industrial, and military applications.

DF Series compact one amp, single-phase, full-wave bridge rectifiers, introduced in August 2000, have unique power-to-volume ratios designed to provide greater power density in high-volume industrial and consumer electronic devices.

Texas Instruments, Inc. acquired **Burr-Brown Corporation** in a stock-for-stock transaction valued at approximately $7.6 billion. The acquisition strengthens TI's position in the data converter and amplifier segments of the analog semiconductor market. This is the third acquisition TI has made in the past 12 months to expand and build its leadership in catalog analog semiconductors (Unitrode in October 1999, and Power Trends in November 1999).

New from **Thermagon, Inc.**:
T-guide for Performance. This comprehensive design guide was created to maximize the benefits of Thermagon's T-lam™ Insulated Metal Printed Circuit Board (IMPCB™) material. It also expands on the secondary electrical and mechanical advantages of Thermagon's T-preg™ material.

New from **IXYS Corporation**:
900V current regulator. Available in two packages, the IXCY10M90S comes in the TO-252 package, while the IXCP10M90S is in a TO-220 package. Typical applications include over-voltage and over-current protection for sensitive loads, inrush current limiters, soft-start applications, and adjustable current regulators.

New from **Ault Inc.**:
External 90 Watt switch-mode power supply (SMPS). The PW116 expands Ault's switch-mode, linear, transformer, and battery charger lines. The desktop-style 90W unit is currently available in 24V and 48V models with input voltage of 100VAC to 250VAC.

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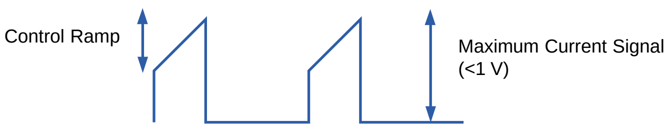

Fig. 6a: Ideal Current Waveforms

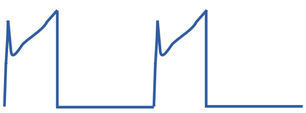

Fig. 6b: Practical Circuit Current Waveforms

Current-mode control, when properly implemented, is the preferred approach for a rugged power supply. However, the signal-to-noise problems cannot be fixed in all cases across the entire range of power supply operation. For those exceptions, you can accept current-mode control with some regions of chaotic operation (although controlled chaotic with output voltage still regulated), or use voltage-mode, accepting its limitations.

References:

[1] C.W. Deisch, "Switching Control Method Changes Power Converter into a Current Source", IEEE Power Electronics Specialists Conference, 1978 Record.
[2] R.B. Ridley, "A More Accurate Current-Mode Control Model", available at www.ridleyengineering.com.