SAM DAVIS, Editor in Chief

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Adaptive On-Time DC-DC Converters Combine Speed and Efficiency

Advanced control loop adjusts the on-time based on input and output voltages, resulting in pseudo-fixed frequency operation with ±15% accuracy and predictable EMI.

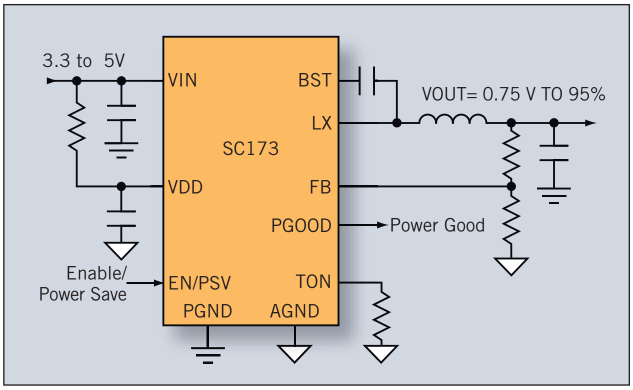
SEMTECH CORP.'S newest EcoSpeed™ dc-dc converters are the SC173 and SC174 synchronous buck regulators. Their dc-dc converter platform incorporates a patented adaptive on-time (AOT) topology intended primarily for point-of-load (POL) applications. The SC173 and SC174 POL regulators satisfy today's "green" power requirements by efficiently managing both standby and full current demands. Typical applications include office automation, networking and communications equipment; set-top boxes; portable products; power supply modules; and other embedded products.

Figure 1 is a typical configuration of the SC173 regulators. The SC174 configuration is similar, the only difference is their output, the SC173 can supply 3A and the SC174 can supply 4A. Their programmable switching frequency range of 200KHz to 1MHz enables circuit optimization for minimum board space and optimum efficiency.

The SC173 and SC174 converters exhibit advantages over conventional constant on-time control topologies, as shown in *Table 1* that compares their characteristics. The adaptive on-time topology in common with hysteretic topologies, enables fast transient response while eliminating the need for external compensation components. This results in simple, space- and cost-efficient power management solutions. However, compared with constant on-time and hysteretic topologies, the adaptive on-time technique provides for more predictable switching frequencies.

Figure 2 shows the simplified circuit for pseudo-fixed frequency, adaptive on-time control. When VFB is less than the internal 750mV reference, the FB Comparator output goes high, turning on the high-side MOSFET via the flip-flop and gate drive. The resulting output ripple triggers the one-shot multivibrator, which sends a single pulse to the high-side MOSFET by way of the flip-flop (F/F) and gate drive. One FB comparator input accepts a percentage of VOUT determined by the voltage divider consisting of R1 and R2, its other input accepts the reference voltage (VREF).

You can configure the SC174 with various capacitor types, such as electrolytic, tantalum, POS and ceramic. For some applications that use low-ESR ceramic capacitors, a signal injection circuit may be implemented to provide 10 mVp-p, as shown in *Fig. 3*. The on-time control regulates

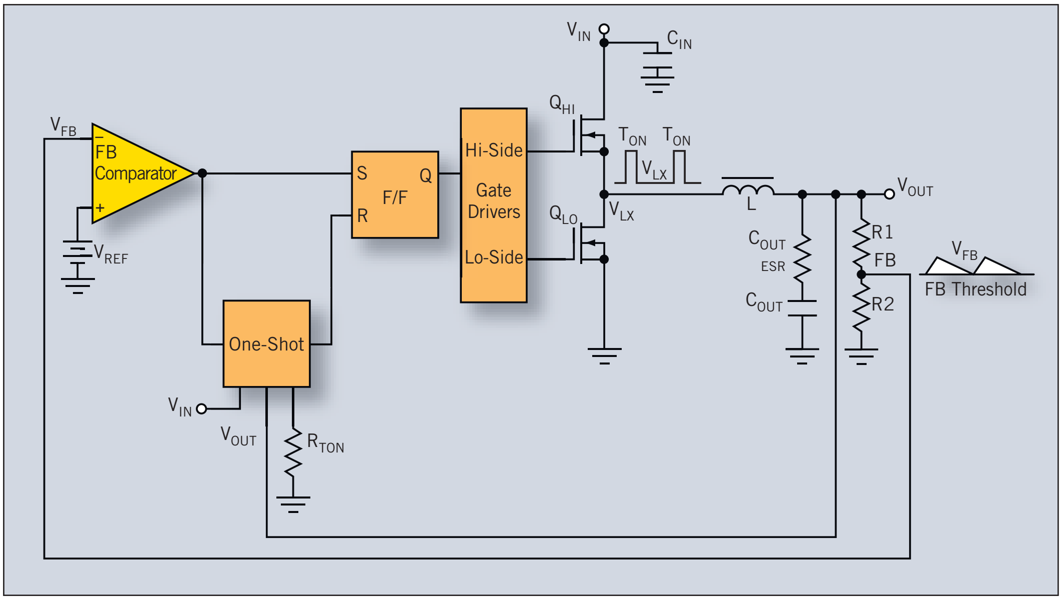


1. The SC173 is an integrated, synchronous 3A step-down regulator with an input voltage range of 3V to 5.5V and a programmable output voltage from 0.75V up to 95% x VIN.

TABLE 1. CHARACTERISTICS COMPARISON OF CONSTANT ON-TIME AND ADAPTIVE ON-TIME TOPOLOGIES

Function	Constant On-Time	Adaptive On-Time
Line Regulation	Excellent	Excellent
Load Regulation	Excellent	Excellent
External Compensation	None	None
Stable Operation with Wide Range of Load Capacitance	No	Yes
Switching Frequency	Variable	Pseudo-Fixed
Transient Response	Ultra-Fast	Ultra-Fast
C_{OUT}	Limited	Flexible
Power Save	Inherent	Inherent

2. Simplified circuit of the SC173 and SC174 employs a comparator, one-shot multivibrator, flip-flop, gate drivers and on-chip power MOSFETs. Use of the one-shot provides adaptive on-time control.



the valley of the output ripple voltage. This ripple voltage is the sum of the two voltages: one produced by the ESR of the output capacitor, and the other due to capacitive charging and discharging of the output capacitor during the switching cycle. For most applications, the output capacitor dominates total output ripple voltage.

In the one-shot multivibrator used in the SC173 and SC174, a current source determined by VIN and RTON charges an internal 2.5pF capacitor. The high-side MOSFET turns off when the capacitor voltage hits VOUT, which is derived internally by the heavily filtered LX voltage. Therefore, at the selected frequency, the IC automatically anticipates the on-time needed to regulate VOUT based on the existing VIN. This method automatically produces an on-time proportional to VOUT and inversely proportional to VIN. Under steady-state operation, you can program the switching frequency from 200kHz to 1MHz, according to:

$$f_{sw} = \frac{V_{OUT}}{T_{ON} \times V_{IN}} \quad (1)$$

The SC173 and SC174 use external resistor RTON to set the on-time, which indirectly sets the frequency. You can determine RTON from the desired switching frequency:

$$R_{TON} = \frac{1}{25pF \times f_{sw}} \quad (2)$$

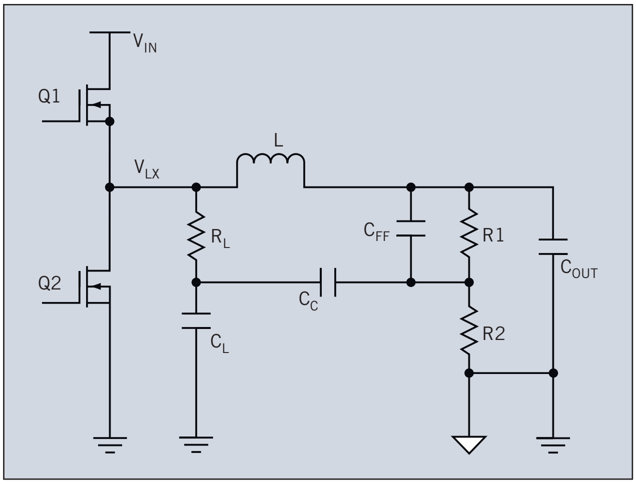
The switcher output voltage (VOUT) is regulated by comparing the internal 750mV reference voltage with the percentage of VOUT determined by the R1 and R2 voltage divider at FB. Adjusting the values of the voltage divider controls VOUT.

Advantages of adaptive on-time control are:

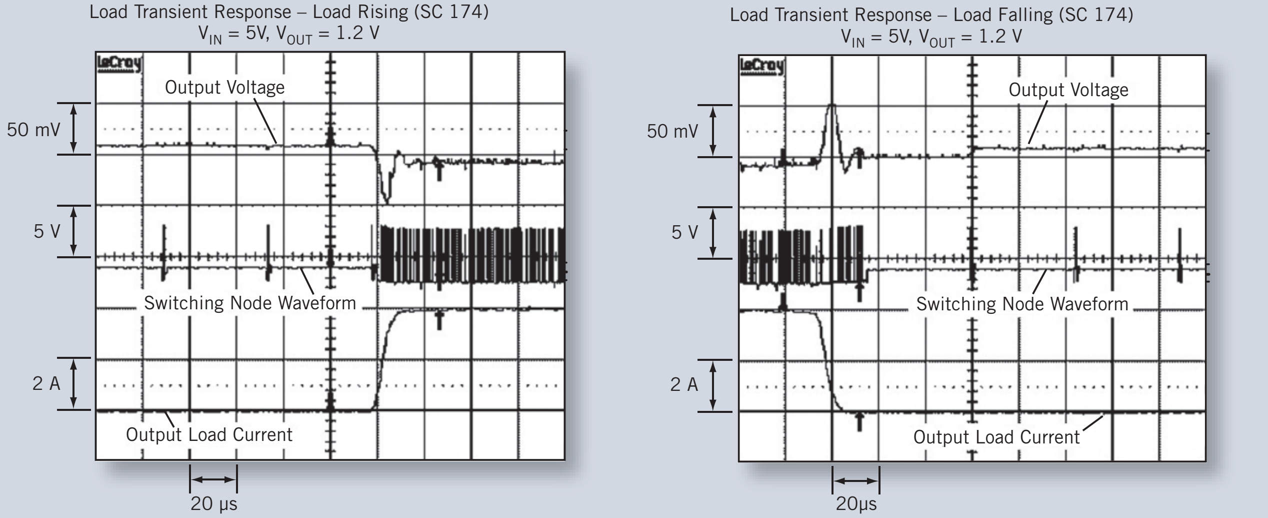
- Predictable operating frequency compared to other variable frequency methods.
- Reduced component count by eliminating the error amplifier and external compensation components.
- Reduced component count by removing the need to sense and control inductor current.
- Fast transient response, controlled by a fast comparator rather than a typically slow error amplifier used in traditional regulator circuits. *Figures 4a and 4b* illustrate the transient response of an SC174 during a rising and falling load current.
- Operates with ceramic input and output capacitors.
- Reduced output capacitance due to fast transient response

LOW STANDBY POWER

Very low power during standby mode is increasingly important to comply with emerging “green” initiatives.



3. Signal injection circuit provides 10 mVp-p at FB.



(a) Output voltage, output current, and switching node waveforms for rising load with VIN = 5V and VOUT = 1.2V.

(b) Output voltage, output current, and switching node waveforms for falling load with VIN = 5V and VOUT = 1.2V.

4. Transient response for the SC174

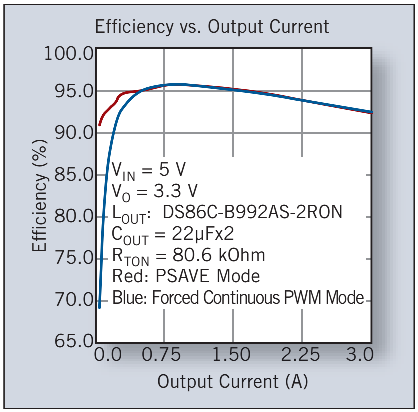
However, most electronic products also require fast "wake-up" capability, which demands fast recovery from low-power standby to full-power steady state mode. The SC173 and SC174 converters solve this with an ultrasonic power-save (UPSAVE) mode. UPSAVE reduces the switching frequency to meet low-power standby requirements, which cuts power MOSFET switching losses and results in up to 95% peak standby efficiency. Then, when the load changes from standby to steady state, the EcoSpeed technology cycle-by-cycle response quickly exits UPSAVE mode. To keep the switching frequency from exceeding 25 kHz (high end of the audible range) on-times are prevented from occurring at intervals greater than 40µs.

You can see the effect of power-save in *Figures 5 and 6* that show the SC173 and SC174 efficiency vs. output current, respectively. The red curve is with power-save and the blue curve is without power-save.

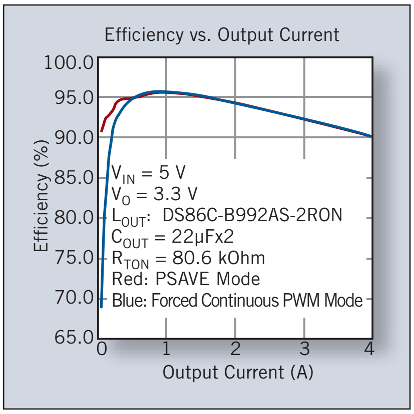
CIRCUIT PROTECTION

Active loads may leak current from a higher voltage into the switcher output. Under light load conditions with power-save enabled, this can force VOUT to slowly rise and reach the over-voltage threshold, resulting in a hard shutdown. Smart Power Save prevents this condition. When the FB voltage exceeds 10% above nominal (825mV), the ICs immediately disable power-save, and turn on the low-side MOSFET. This draws current from VOUT through the inductor and causes VOUT to fall. When VFB drops back to the 750mV trip point, a normal TON switching cycle begins. This method prevents a hard over-voltage protection (OVP) shutdown and also cycles energy from VOUT back to VIN.

These ICs feature fixed current limiting that employs the RDS(ON) of the lower MOSFET for current sensing. While the low-side MOSFET is on, the inductor current flows through it and creates a voltage across its RDS(ON). During



5. Efficiency vs. output current for the SC173. Blue line is forced conduction mode efficiency. Red line is efficiency with Power-Save.



6. Efficiency vs. output current for the SC174. Blue line is forced conduction mode efficiency. Red line is efficiency with Power-Save.

this time, the voltage across the MOSFET is negative with respect to ground. If this MOSFET voltage drop exceeds the internal reference voltage, it activates the current limit. The current limit then keeps the low-side MOSFET on and will not allow another high side on-time, until the current in the low-side MOSFET reduces enough to drop below the internal reference voltage once more.

ADDITIONAL PROTECTION FEATURES

The SC173 and SC174 synchronous buck regulators incorporate a full range of protection features, including:

- Over-Voltage Protection (OVP)
- Over-Temperature Protection (OTP)
- Output short circuit protection
- Under-voltage lock-out (UVLO)
- Soft-Start

To indicate that the SC173 and SC174 are operating properly, the regulators provide a power good (PGOOD) output, with open-drain that requires a pull-up resistor. When the output voltage is 10% below the nominal voltage, PGOOD goes low and stays low until the output voltage returns to the nominal voltage. PGOOD is held low during soft start and activated approximately 1ms after VOUT reaches regulation. The total PGOOD delay is typically 2ms.

PGOOD will transition low if VFB exceeds +20% of nominal, which is also the over-voltage shutdown threshold (900mV). PGOOD also pulls low if the EN/PSV pin is low when VDD is present.

SUMMARY

Designers wishing to implement point-of-load power circuits now have an energy-saving alternative in the SC173 and SC174 synchronous buck regulators. The parts efficiently manage current in standby and full current modes, using an advanced adaptive on-time topology to provide fast transient response, reduced output capacitance, and predictable switching frequencies.

ECOSPEED FAMILY PORTRAIT

THE SC173 AND SC174 are the newest introductions of Semtech's EcoSpeed family. Table 2 lists the other members of the family that will follow. Some of these ICs have internal Power MOSFETs, whereas others will require external MOSFETs. Those intended for external MOSFETs have an asterisk in the IOUT (max) column of Table 2.

Similar to the other AOT converters, the SC493 is also a synchronous buck power supply controller, except that it has an I^{2}C interface. This can be used to program output voltage offset, power-on delay time, soft-start time, power save operating mode, and can enable/disable the controller. Also, a status register provides information on device state and faults.

TABLE 2. SEMTECH'S ECOSPEED FAMILY OF DC-DC CONVERTERS

Part No.	Type	On-Chip LDO	V_{IN} Range (V)	V_{DD} Range (V)	V_{OUT} Range (V)	I_{OUT} (max.) (A)	P_{GOOD}	Enable	Selectable P_{SAVE}	Package (mm)
SC173	Regulator	No	3.0-5.5	3.0-5.5	0.75 to 95% V_{IN}	3	Yes	Yes	Ultrasonic	MLPD-10 (3 x 3 x1)
SC174	Regulator	No	3.0-5.5	3.0-5.5	0.75 to 95% V_{IN}	4	Yes	Yes	Ultrasonic	MLPD-10 (3 x 3 x1)
SC414	Regulator	Yes	3.0-5.5	3.0-5.5	0.75 to 5.25	6	Yes	Yes	Ultrasonic	MLPQ-28 (4 x 4 x1) MLPQ-32 (5 x 5 x1)
SC417	Regulator	Yes	3.0-28	4.5-5.5	0.5 to 5.25	10	Yes	Yes	Ultrasonic	MLPQ-32 (5 x 5 x1)
SC418	PWM Controller	Yes	3.0-28	3.0-5.5	0.5 to 5.25	30*	Yes	Yes	Programmable Ultrasonic or Regular	MLPQ-UT-20 (3 x 3 x0.6)
SC419	PWM Controller	No	3.0-28	4.5-5.5	0.5 to 5.25	30*	Yes	Yes	Programmable Ultrasonic or Regular	MLPQ-UT-20 (3 x 3 x1)
SC424	Regulator	Yes	3.0-28	3.0-5.5	0.75 to 5.25	6	Yes	Yes	Regular	MLPQ-28 (4 x 4 x1)
SC427	Regulator	Yes	3.0-28	4.5-5.5	0.5 to 5.25	10	Yes	Yes	Regular	MLPQ-32 (5 x 5 x1)
SC493	I^{2}C Controller	No	3.0-28	3.0-5.5	0.5 to 3.3	30*	Yes	Yes	Programmable Ultrasonic or Regular	MLPQ-UT-20 (3x 3 x0.6)