

Compact No R_{SENSE} Controllers Feature Fast Transient Response and Regulate to Low V_{OUT} from Wide Ranging V_{IN}

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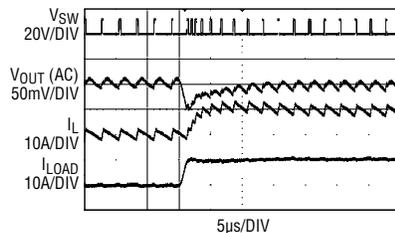
Introduction

The trend in digital electronics is to lower voltages and increasing load currents. This puts pressure on DC/DC converters to produce low voltages from increasingly voltage-variable supplies, such as stacked batteries and unregulated intermediate power buses, so power converters must be optimized for low output voltages, low duty factors, and wide control bandwidths. To meet these requirements, the DC/DC controller IC must offer high voltage accuracy, good line and load regulation, and fast transient response. The constant on-time valley current mode architecture used in the LTC3878 and LTC3879 is ideally suited to low duty factor operation, offering a compact solution with excellent system performance.

The LTC3878 and LTC3879 are a new generation of No R_{SENSE} ™ controllers that meet the demanding requirements of low voltage supplies for digital electronics. The LTC3878 is a pin compatible replacement for the LTC1778 in designs where $EXTV_{CC}$ is not required. The LTC3879 adds separate RUN and TRACK/SS pins for applications requiring voltage tracking. Both devices offer continuously programmable current limit, using the bottom MOSFET V_{DS} voltage to sense current.

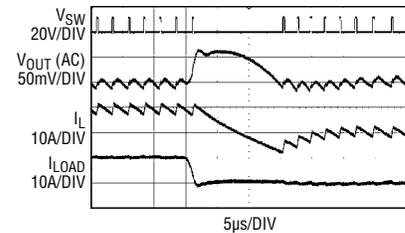
Valley Current Mode Control Simplifies Loop Compensation...

There are two common implementations of current mode control. Peak current mode control regulates the high side MOSFET on-time, while valley current mode regulates the bottom side MOSFET off-time. The current mode loop bandwidth is in-



LOAD STEP 0A TO 10A
 $V_{IN} = 12V$
 $V_{OUT} = 1.2V$
 MODE = 0V
 SW FREQ = 400kHz

Figure 1. Transient response, positive load step



LOAD STEP 10A TO 0A
 $V_{IN} = 12V$
 $V_{OUT} = 1.2V$
 MODE = 0V
 SW FREQ = 400kHz

Figure 2. Transient response, load release

versely proportional to the on-time for a peak current controller and inversely proportional to the off-time for a valley mode controller. A peak current mode controller with an on-time of 50ns must have a closed current loop bandwidth exceeding 20MHz. For a valley current mode controller, the current loop bandwidth is determined by the typical off-time of 220ns, resulting in a closed current loop bandwidth requirement of only 4.5MHz. Consequently, valley current mode control has less stringent bandwidth requirements for the same system performance when compared to a peak current mode control in a similar application. This allows the LTC3878 and LTC3879 to offer high performance, low duty factor operation at reasonable current loop bandwidths.

The constant on-time valley current mode control of the LTC3878 and LTC3879 simplifies compensation design by eliminating the need for slope compensation. A fixed frequency valley mode controller requires slope compensation when operating at less than 50% duty factor to prevent sub-cycle oscillation. Subcycle oscillation occurs because the PWM pulse width

is not uniquely determined by inductor current alone. This oscillation cannot exist in constant-on-time control because the PWM pulse width is uniquely determined by the internal open loop pulse generator. True current mode control and constant on-time combine to give the LTC3878 and LTC3879 performance advantages over other constant on-time regulators or fixed frequency valley current mode control architectures.

...and Improves Transient Response Time

In a buck controller, transient response is largely determined by how quickly the inductor current responds to loop disturbances. The most demanding loop disturbances are load steps and load releases.

The inherent speed advantage of a constant on-time architecture lies in the fact that the regulator is pulse frequency modulated (PFM) instead of pulse width modulated (PWM). Although the switching frequency is fixed in steady state operation, it can increase or decrease as required in response to an output load step or load release.

The maximum frequency in response to a load step is determined by the on-time plus the off-time:

$$f_{MAX} = \frac{1}{(t_{ON} + t_{OFF(MIN)})} \text{ (Hz)}$$

In low duty factor applications the maximum frequency is typically much greater than the nominal operating frequency, producing excellent transient characteristics.

Figure 1 shows the load step response of a 12V-to-1.2V converter operating at 400kHz. In this case the on-time is equal to 250ns and the minimum off-time is 220ns. The maximum frequency available to respond to a load step is 2.12MHz, which is over five times the nominal switching frequency. Note the increase in switching frequency of the V_{SW} waveform in response to the 10A load step. The increase in switching frequency causes the inductor current to ramp faster in constant on-time PFM controllers than is possible in a true fixed frequency PWM.

In response to a load release (Figure 2), the minimum frequency is effectively zero, since the bottom gate is held high as long as needed to ramp the inductor current down to the internal regulation set point. In this example, the inductor current ramps from 11A to -8A in 13µs as the output recovers from the load step. For both load transient cases, variable frequency has an inherent speed advantage over fixed frequency in transient recovery.

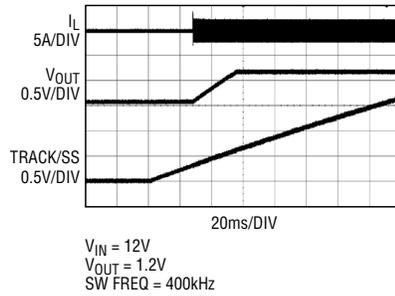


Figure 3. Start-up into a prebiased output

Transient settling requires both the large signal ramping of inductor current and the stable settling of the output to the desired regulation point. Excessive output overshoot or ringing indicates marginal system stability likely caused by inadequate compensation. A rough compensation check can be made by calculating the gain crossover frequency, given by the following equation (where $V_{REF} = 0.8V$ for the LTC3878 and $V_{REF} = 0.6V$ for the LTC3879):

$$f_{CGO} = g_m(EA)R_C \frac{I_{LIMIT}}{1.6} \cdot \frac{1}{C_{OUT}} \cdot \frac{V_{REF}}{V_{OUT}}$$

As a rule of thumb, the gain crossover frequency should be less than 20% of the switching frequency. With any analog system, transient response is determined by closed loop bandwidth. In order to optimize for transient performance, it is desirable to have a small inductor and a wide closed loop bandwidth. A small inductor is desired for quick output current response, while the closed loop bandwidth and phase margin determines how quickly the output settles after a load step.

Start-Up Options

The LTC3878 offers the simplicity of current limited start-up through the combined RUN/SS pin. When RUN/SS is greater than 0.7V all internal bias is activated. Once RUN/SS exceeds 1.5V, switching begins. The current limit is gradually increased as the RUN/SS pin voltage ramps until reaching full output at approximately 3V.

The LTC3879 adds the flexibility of separate RUN and TRACK/SS pins. All internal bias is activated when RUN exceeds 0.7V. Switching begins when RUN exceeds 1.5V. The TRACK/SS pin can also be used for input voltage tracking, where the LTC3879's output tracks the voltage on the TRACK/SS pin until it exceeds 0.6V. Once TRACK/SS exceeds 0.6V the output regulates to the internal 0.6V reference. An internal 1µA pull-up current is available to create a soft-start voltage ramp when a small capacitor is connected to TRACK/SS. Together, RUN and TRACK/SS enable a number

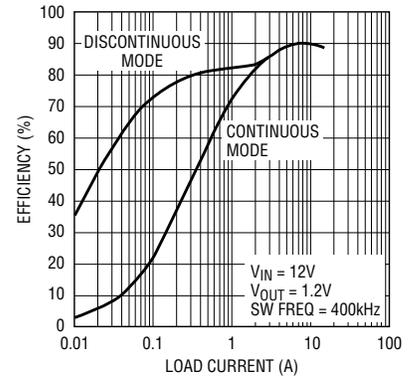


Figure 4. Efficiency for application in Figure 5

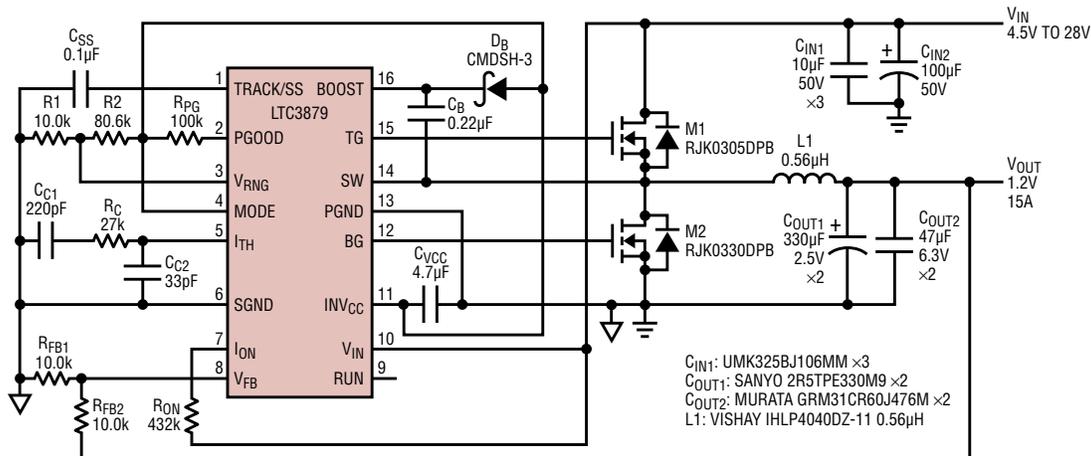


Figure 5. Wide input range to 1.2V at 15A, operating at 400kHz

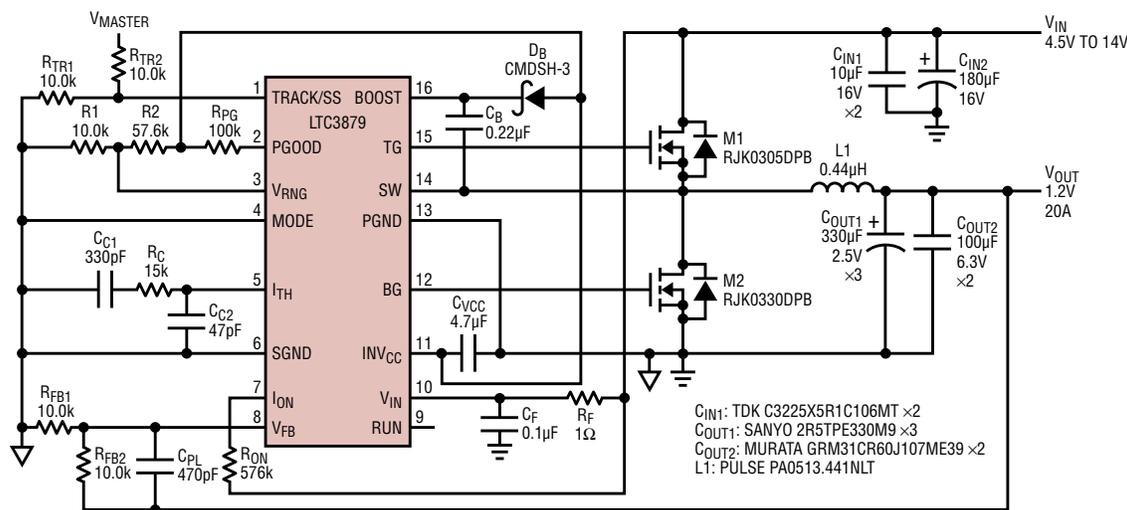


Figure 6. Coincident tracking example produces 1.2V at 20A, operating at 300kHz

of start-up supply sequencing and tracking options.

Both the LTC3878 and LTC3879 have the ability to start up onto pre-biased outputs. Because current limit is ramped in the LTC3878, prebiased output voltages are not an issue. The LTC3879 output tracks the input on the TRACK/SS pin. To accommodate prebiased outputs, the LTC3879 will not switch until the TRACK/SS pin exceeds the V_{FB} voltage. Once TRACK/SS exceeds V_{FB} the output follows the TRACK/SS pin in continuous conduction mode until the output regulates to the internal reference.

In Figure 3 the LTC3879 output is prebiased to 0.5V. The TRACK/SS pin ramps from zero and crosses the prebiased output feedback point at approximately 28ms, when switching begins. Once switching begins the output enjoys a smooth soft-start ramp. The LTC3879 operates in continuous conduction mode during start-up, regardless of the mode setting, allowing regulation of the output voltage to the TRACK/SS input pin voltage during soft-start.

High Efficiency

The LTC3878 and LTC3879 offer excellent efficiency through the combination of strong gate drivers and short dead time. The top gate driver offers a 2.5Ω pull up resistance and a 1.2Ω pull down, while the bottom gate driver offers a 2.5Ω pull up and a 0.7Ω pull

down. Dead time has been measured as low as 12ns, minimizing switching loss. Efficiency has been measured at 91.8% in a 1.2V/20A application.

The LTC3878 and LTC3879 offer both discontinuous conduction mode (DCM) and continuous conduction mode (CCM) operation. Figure 4 shows peak efficiency over 90% for 12V and 15A in CCM. In CCM, either the top MOSFET or the bottom MOSFET is active and the output inductor is continuously conducting. In DCM, the top and bottom MOSFET can be off simultaneously in order to improve low current efficiency. In Figure 4, at 100mA, the efficiency is greater than 70% in DCM, compared to only 20% in CCM. Improvements in efficiency in DCM are seen when the load is less than the DC average of the steady state ripple current, causing the regulator to enter discontinuous conduction.

Application Example: 4.5V-to-28V In to 1.2V Out with 90% Peak Efficiency

Figure 5 shows an application that converts a wide 4.5V-to-28V input voltage to a 1.2V ±5% output at 15A. The nominal ripple current is chosen to be 35% resulting in a 0.55μH inductor and ripple current of 5.1A. Because the top MOSFET is on for a short time, an RJK0305DPB ($R_{DS(ON)} = 10m\Omega$ (nominal), $C_{MILLER} = 150pF$, $V_{MILLER} = 3V$) is sufficient. The stronger RJK0330DPB is chosen for the bottom MOSFET, with

a typical $R_{DS(ON)}$ of 3.8mΩ. This results in 90% peak efficiency. Note that the efficiency, transient and start-up waveforms in Figures 1–4 were taken from this design example.

Tracking

Figure 6 shows a LTC3879 in a 1.2V/20A output, 300kHz application design with coincident rail tracking. In coincident tracking, two supplies ramp up in unison until the lower voltage supply reaches regulation, at which point the higher voltage supply continues to ramp to its regulated value. Coincident tracking is implemented by making the resistor divider from the master voltage to the TRACK/SS pin equal to the feedback divider from V_{OUT} to V_{FB} . In Figure 6, the output is 1.2V, so the divider is equal to 0.6V/1.2V, or 0.5. This design tracks any master supply that is equal to or greater than 1.2V. The TRACK/SS pin should be greater than 0.65V in regulation to ensure that the LTC3879 has sufficient

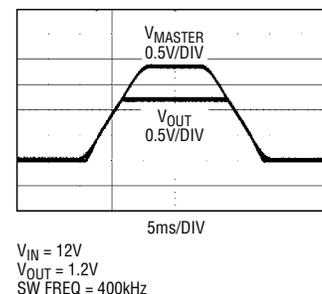


Figure 7. Coincident tracking waveforms for application in Figure 6

margin to switch from tracking the TRACK/SS input voltage to regulating to the internal reference.

Figure 7 shows typical tracking waveforms of the application in Figure 6. V_{OUT} and the reference supply voltage, V_{MASTER} , are equal and track together during start-up until they reach 1.2V, at which point V_{OUT} regulates to 1.2V while V_{MASTER} continues ramping to 1.8V.

Conclusion

The LTC3878 and the LTC3879 support a V_{IN} range from 4V to 38V (40V abs max). The regulated output voltage is programmable from 90% V_{IN} down to

0.8V (for the LTC 3878) and 0.6V (for the LTC3879). The output regulation accuracy is $\pm 1\%$ over the full -40°C to 85°C temperature range. The operating frequency is resistor programmable and is compensated for variations in V_{IN} . Current limit is continuously programmable and is measured without a sense resistor by using the voltage drop across the external synchronous bottom MOSFET.

The valley current mode architecture is ideal for low duty factor operation and allows very low output voltages at reasonable current loop bandwidths. Compensation is easy to design and offers robust and stable

operation even with low ESR ceramic output capacitors. The LTC3878 offers current limited start-up, while the LTC3879 has separate run and output voltage tracking pins. The LTC3878 is available in the GN16 package, and the LTC3879 is available in thermally enhanced MSE16 and QFN (3mm \times 3mm) packages. Excellent performance and compact size make the LTC3878 and LTC3879 well suited to small, tightly constrained applications such as distributed power supplies, embedded computing and point of load applications. 

LT3757/58, continued from page 4

An 18V-72V Input, 5V/2A Output Isolated Flyback Converter

The basic design shown in Figure 7 can be modified to provide DC isolation between the input and output with the addition of a reference, such as the LT4430, on the secondary side of the transformer and an optocoupler

to provide feedback from the isolated secondary to the LT3758. Figure 8 shows an 18V-72V input, 5V/2A output isolated flyback converter.

Conclusion

The LT3757 and LT3758 are versatile control ICs optimized for a wide variety of single-ended DC/DC converter to-

pologies. Both offer a particularly wide input voltage range. These ICs produce space saving, cost efficient and high performance solutions in any of these topologies. The range of applications extends from single-cell, lithium-ion powered systems to automotive, industrial and telecommunications power supplies. 

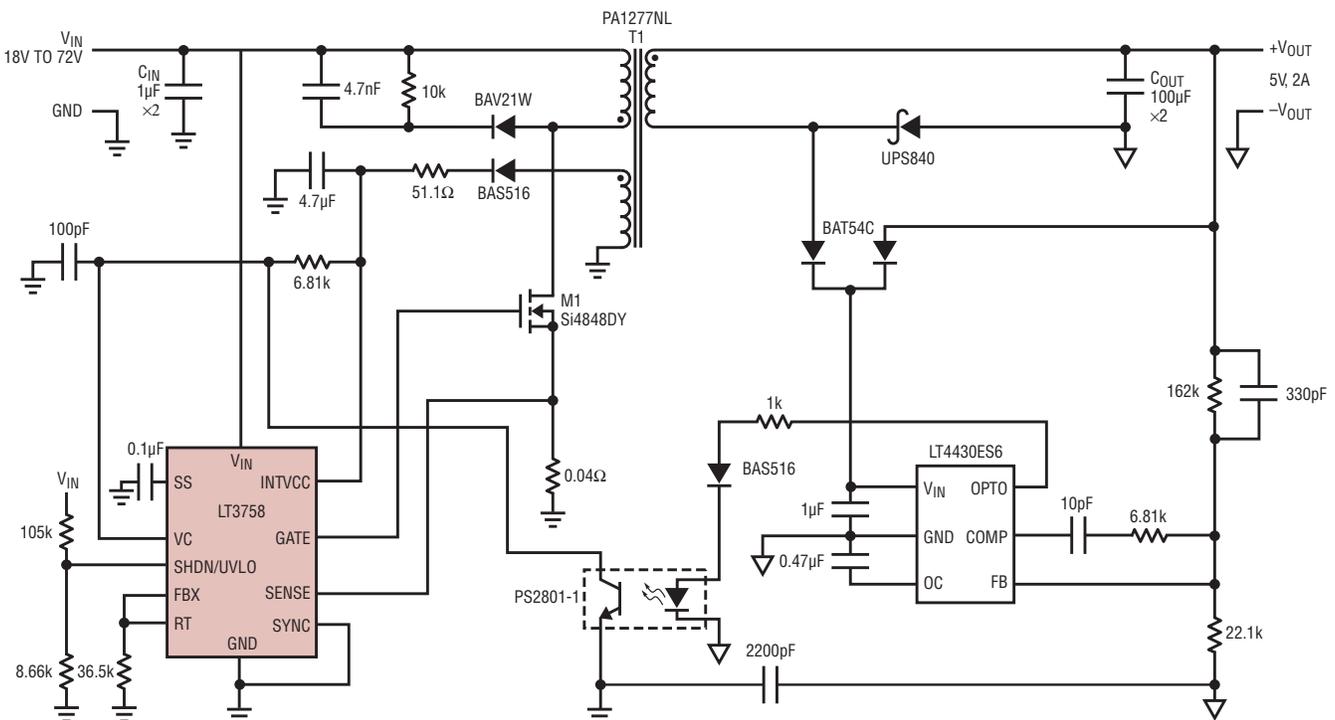


Figure 8. 18V-72V input, 5V/2A isolated flyback converter