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# Monolithic Synchronous Step-Down Regulators Pack >500mA Output Current in an MS8 Package

by Jaime Tseng and Gary Shockey

## Introduction

The quest to pack more power into portable electronic devices while shrinking their size has placed increased demands on power management products. Not only must they be physically smaller, but they must also retain the power handling capability of their older, larger counterparts. The LTC1877, LTC1878 and LT®1612 are the first of a new generation of monolithic synchronous step-down switching regulators capable of supplying more than 500mA of output current in an MS8 package. Their internal synchronous switches increase efficiency and eliminate the need for external Schottky diodes, saving external components and board space. Optimized for battery-powered applications, the LTC1877 works with a supply range of 2.65V to 10V, the LTC1878 works with supplies of 2.65V to 6V and the LT1612 works with supplies of 2V to 5.5V. This wide operating supply range covered by the two parts allows the use of a single or dual Li-Ion battery or 2- to 6-cell NiCd and NiMH battery packs.

## LTC1877/LTC1878 vs LT1612

The LTC1877 and LTC1878 are designed in Linear Technology's high

performance BiCMOS process and are optimized for ultrahigh efficiency at low load currents. The DC supply currents of both parts are only 10µA while maintaining the output voltage (using Burst Mode™ operation) at no load. This enables both parts to maintain better than 90% efficiency over three decades of output load current. The LT1612, designed in Linear Technology's high speed bipolar process, is optimized for low voltage operation and is a lower cost alternative to the LTC1877/LTC1878. The LT1612 can still regulate the output while supplying 500mA to the load with input supply voltages as low as 2V. The internal frequency is set to 800kHz, compared to 550kHz for the LTC1877. The DC supply current is 150µA. Placing the part in shutdown reduces the current to 1µA.

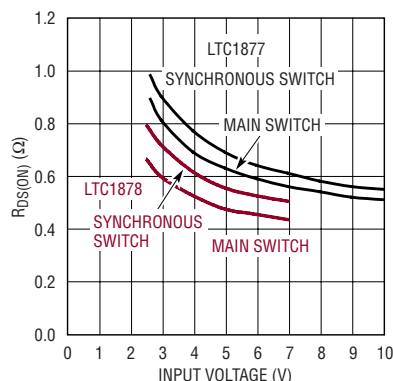
## A Detailed Look at the LTC1877/LTC1878

The LTC1877 and LTC1878 are two nearly identical parts in that they have exactly the same functionality, architecture and pinout. What distinguishes the two parts is their maximum supply voltages: the

*continued on page 3*



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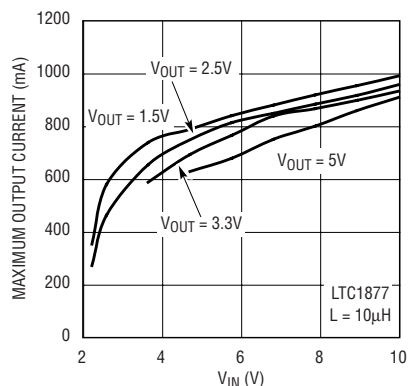
**Figure 1.  $R_{DS(ON)}$  for both switches vs input voltage**

LTC1877/LT1612, continued from page 1

LTC1877 is designed for higher input voltage applications, whereas the LTC1878 is optimized for lower input voltage applications. For example, the LTC1877 provides up to 600mA of output current at an input voltage of 5V, whereas the LTC1878 provides the same amount of current at an input voltage of only 3.3V.

Both the LTC1877 and LTC1878 incorporate a constant frequency, current mode step-down architecture with on-chip power MOSFETs.

The LTC1877/LTC1878 include protection against output overvoltage, output short-circuit and power overdissipation conditions. When an overvoltage condition at the output (>6.25% above nominal) is sensed, the top MOSFET is turned off until the fault is removed. When the output is shorted to ground, the frequency of the oscillator slows to prevent inductor-current runaway. The frequency slows to about 80kHz or one-seventh of the nominal frequency. The frequency returns to 550kHz (or the

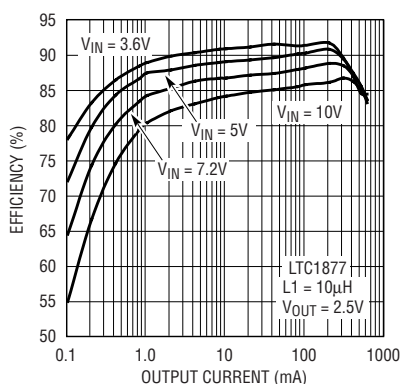


**Figure 2. Maximum output current vs input voltage**

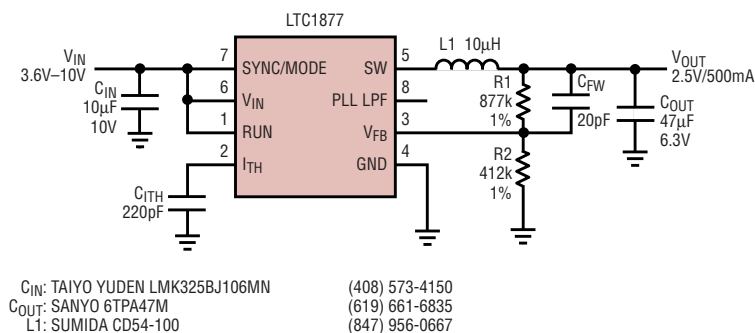
external synchronized frequency) when  $V_{FB}$  is allowed to rise to 0.8V. When there is a power overdissipation condition and the junction temperature reaches approximately 145°C, the thermal protection circuit turns off the power MOSFETs allowing the LTC1877/LTC1878 to cool. Normal operation resumes when the temperature drops by 10°C.

### Burst Mode Operation

The LTC1877/LTC1878's Burst Mode operation is enabled by simply strapping the SYNC/MODE pin to  $V_{IN}$  or connecting it to a logic high ( $V_{SYNC/MODE} > 1.2V$ ). In this mode, the peak current of the inductor is set to approximately 250mA, even though the voltage at the  $I_{TH}$  pin (the output of the error amplifier) would reflect a lower value. The voltage at the  $I_{TH}$  pin drops when the inductor's average current is greater than the load requirement. When the  $I_{TH}$  voltage drops below approximately 0.6V, a sleep signal is generated, turning off both power MOSFETs. The  $I_{TH}$  pin is



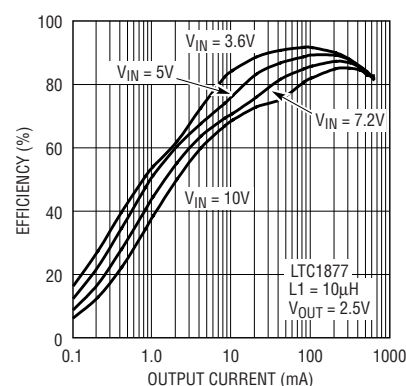
**Figure 4. Efficiency vs load current for Figure 3's circuit (Burst Mode operation enabled)**



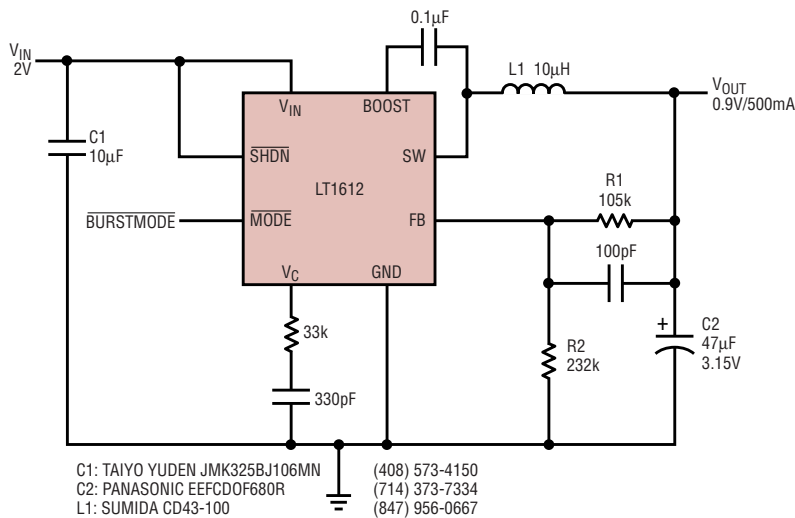
**Figure 3. 2.5V/500mA step-down regulator**

then disconnected from the output of the error amplifier and "parked" a diode voltage above ground. During this time, the internal circuitry is partially turned off, reducing the quiescent current to 10µA; the load current is now supplied by the output capacitor. When the output voltage drops by an amount dependent on the output voltage (on the order of 10mV for a 2.5V output), the  $I_{TH}$  pin reconnects to the output of the error amplifier, the top MOSFET is again turned on and the process repeats.

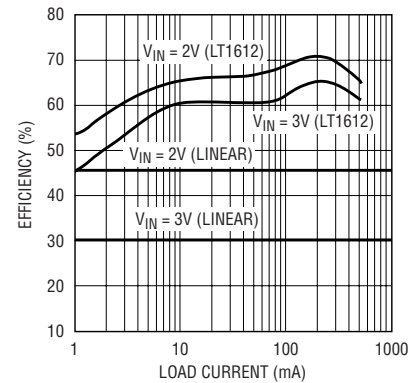
For frequency-sensitive applications, Burst Mode operation is disabled by connecting the SYNC/MODE pin to GND. In this case, constant-frequency operation is maintained at lower load currents together with lower output ripple. If the load current is low enough, cycle skipping will eventually occur to maintain regulation. In this mode, the efficiency will be lower at light loads, but becomes comparable to Burst Mode operation when the output load exceeds 50mA.



**Figure 5. Efficiency vs load current for Figure 3's circuit (Burst Mode operation disabled)**



**Figure 6. 2V to 0.9V step-down converter**



**Figure 7. Efficiency curves for the LT1612 2V to 0.9V converter and a theoretical linear regulator**

## Frequency Synchronization

A phase-locked loop (PLL) on the LTC1877/LTC1878 allows the oscillator to be synchronized to an external source connected to the SYNC/MODE pin. The output of the phase detector at the PLL LPF pin operates over a 0V to 2.4V, range corresponding to 400kHz to 700kHz. When locked, the PLL aligns the turn-on of the top MOSFET to the rising edge of the synchronizing signal. Burst Mode operation is disabled when the LTC1877/LTC1878 is synchronized to an external source. Frequency synchronization is inhibited when the feedback voltage,  $V_{FB}$ , is below 0.6V. This prevents the external clock from interfering with the frequency fold-back for short-circuit protection.

## Low Input Supply and Operation in Dropout

The LTC1877/LTC1878 can operate on an input supply voltage as low as 2.65V. However, the maximum allowable output current is reduced at this low voltage due to an increase in the  $R_{DS(ON)}$  of the P-channel MOSFET. See Figure 1 for a graph of switch resistance vs input voltage. Figure 2 shows the reduction in the maximum output current as a function of input voltage for various output voltages.

The LTC1877/LTC1878 is capable of turning the main P-channel MOSFET on continuously (100% duty cycle) when the input voltage falls to near the output voltage. In this dropout mode, the output voltage is determined by the input voltage minus the voltage drop across the

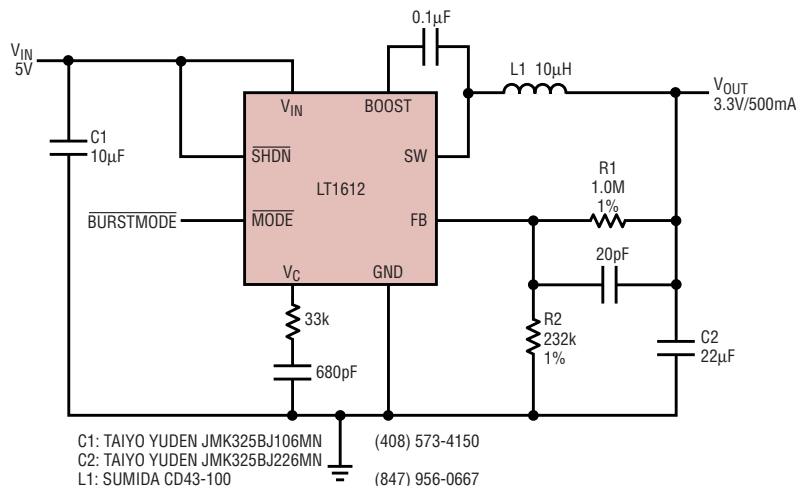
internal MOSFET and the inductor resistance.

## 2.5V/500mA Step-Down Regulator

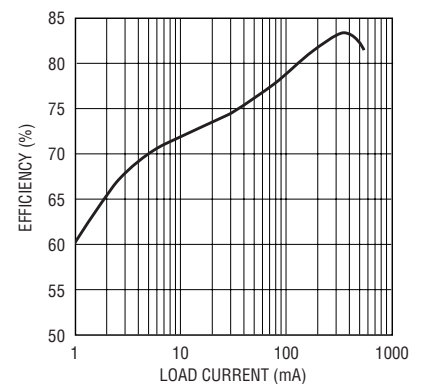
A typical circuit using the LTC1877 is shown in Figure 3. This design supplies a 500mA load at 2.5V with an input supply between 3.6V and 10V. The circuit operates at the internally set frequency of 550kHz. A 10µH inductor is chosen so that the inductor's current remains continuous during burst periods at low load current. For low output voltage ripple, a low ESR capacitor is used. All the components shown in this schematic are surface mount and have been selected to minimize the board space and height.

## Efficiency Considerations

The efficiency curves for the 2.5V/500mA regulator at various supply voltages are shown in Figure 4. Note



**Figure 8. 5V to 3.3V/500mA converter**



**Figure 9. 5V to 3.3V converter efficiency peaks at 83%**

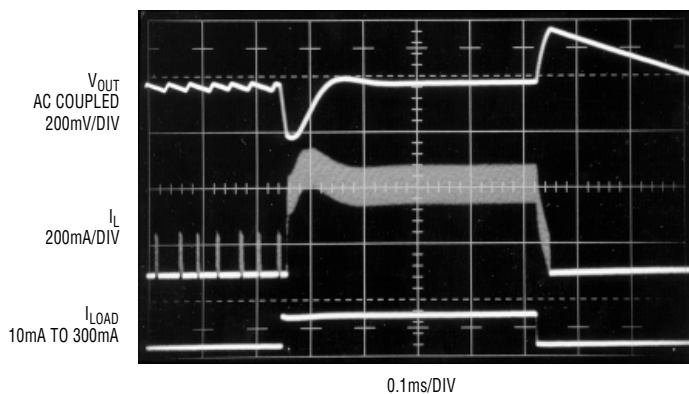


Figure 10. Transient response for Figure 9's circuit

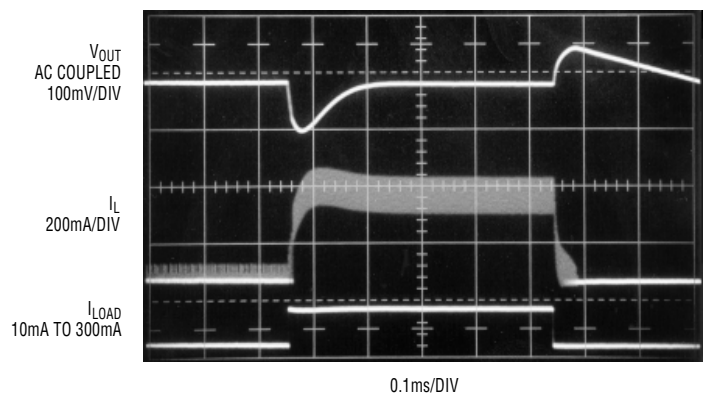


Figure 11. With the  $\overline{\text{MODE}}$  pin high, low frequency ripple at  $V_{\text{OUT}}$  is eliminated

the flatness of the curves over the upper three decades of load current and that the efficiency remains high down to extremely light loads. Efficiency at light loads requires low quiescent current. The curves are flat because all significant sources of loss except for the  $10\mu\text{A}$  standby current— $I^2R$  losses in the switch, internal gate charge losses (to turn on the switch) and burst cycle DC supply current losses—are identical during each burst cycle. The only variable is the rate at which the burst cycles occur. Since burst frequency is proportional to load, the loss as a percentage of load remains relatively constant. The efficiency drops off as the load decreases below about  $1\text{mA}$  because the non-load-dependent  $10\mu\text{A}$  standby current loss then constitutes a more significant percentage of the output power. This loss is proportional to  $V_{\text{IN}}$  and thus its effect is more pronounced at higher input voltages. Figure 5 shows the effect on efficiency of disabling Burst Mode operation.

### LT1612 Details

Like the LTC1877/LTC1878, the LT1612 also uses constant-frequency, current mode control. It is capable of Burst Mode operation or constant-frequency switching. Unlike the LTC1877/LTC1878, it uses bipolar power transistors instead of MOS switches. One of the main design challenges was providing the ability to operate with inputs as low as  $2\text{V}$ .

To achieve this low voltage operation in a buck switching regulator, a bipolar NPN topside power switch is needed, rather than a MOS device. Because the NPN power transistor requires significant base drive current, efficiency is not as high as with its MOS counterpart. Thus, a small sacrifice in efficiency is made for this low voltage operation. The alternative to using the LT1612 to step down from low voltages is to use a linear regulator, which, of course, has its own disadvantages. Linear regulators are inherently inefficient because the power device is operated in the linear region. They must be physically larger to allow for dissipation of the extra heat generated and heat sinks are often needed, even at modest output power.

### Applications

Figure 6 shows the LT1612 converting a  $2\text{V}$  input down to  $0.9\text{V}$ . The internal reference is set at  $0.62\text{V}$ , which allows outputs below  $1\text{V}$ . The graph in Figure 7 compares efficiency for the LT1612 to that of a theoretical linear regulator. At an input voltage of  $2\text{V}$  and a load current of  $200\text{mA}$ , the efficiency is  $70\%$  for the circuit in Figure 6 vs  $45\%$  for the linear regulator. At an input voltage of  $3\text{V}$ , the linear regulator's efficiency is just  $30\%$ , while that of the circuit using the LT1612 drops to  $65\%$ . This clearly illustrates the power savings of the LT1612 as compared to a linear regulator.

The LT1612 is also well suited for more general purpose applications, such as the circuit shown in Figure 8. Here, the LT1612 is shown stepping down  $5\text{V}$  to  $3.3\text{V}$ . Efficiency, graphed in Figure 9, reaches  $83\%$  at a load current of  $300\text{mA}$ . Maximum output power for this configuration is nearly  $2\text{W}$ . Figure 10 shows transient response to a  $300\text{mA}$  load step with Burst Mode enabled. If low noise operation is desired, the  $\overline{\text{MODE}}$  pin can be pulled high, giving the response seen in Figure 11. The low frequency output voltage ripple is now eliminated.

### Conclusion

The LTC1877/LTC1878 and LT1612 are well suited for medium to low power step-down applications with tight board space requirements. These synchronous buck regulators can deliver  $500\text{mA}$  of output current and cover the input voltage range of  $2\text{V}$  to  $10\text{V}$ . The LTC1877/LTC1878 switch at  $550\text{kHz}$  and offer the highest performance possible with efficiency exceeding  $90\%$ . An internal phase-locked loop allows frequency synchronization from  $400\text{kHz}$  to  $700\text{kHz}$ . The LT1612 operates at  $800\text{kHz}$  and exhibits less than one fourth the power loss of a linear regulator at an input of  $3\text{V}$ . All three parts come in the MS8 package and require minimal external components, which allows them to meet the tightest space requirements. 