Extend the Run Time of Your Multi-Tasking Smartphone Design

Introduction

High-performance multicore CPUs with integrated graphics processing units have made their way into smartphones. Smartphones now carry capabilities we used to expect from high-end audio/video equipment and desktop computers. Today's smartphones have 4K video capture, high-end gaming, program multi-tasking, virtual reality functions, and higher display resolution. While these are great features from the user's perspective, they require large amounts of computation, resulting in high system power consumption that generates a lot of heat. To compound this problem, the hardware must fit volumetrically into small form factors, making it difficult to dissipate that heat. This article reviews the challenges of feeding the smartphone's power hungry processors and presents a state-of-the-art solution to address them. Figure 1 shows an 8-core CPU chip for smartphones and tablets.

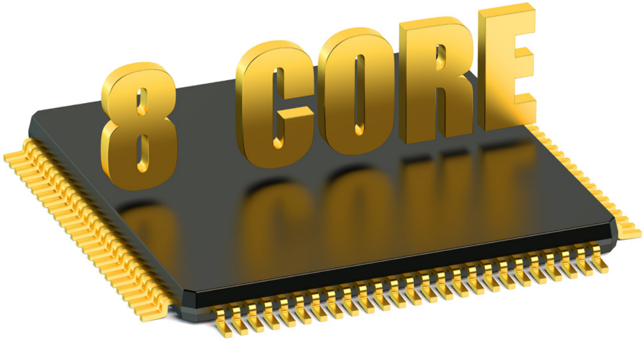

Figure 1. CPU Core Chip for Smartphones and Tablets

More Power to the Buck Converter

In relation to the trends outlined above, the buck converter that powers these processors has evolved from a single-phase device that delivers a few hundred milliamperes of current to a multiphase device that can successfully deliver over tens of Amperes of current. Even so, a state-of-the-art smartphone typically has a battery capacity slightly above 2000mAh. This means that if it consumed a single Ampere of continuous current, it would last only two hours, let alone the widely expected full day of operation. The magic then resides in strict power and thermal management that minimizes wasted power and controls temperature rise by delivering the necessary power peaks when required and immediately retreating into low power modes of operation.

The Thermal Challenge

As an example, a PCB-mounted processor with a junction-to-ambient thermal resistance $R = 50°C/W$ and a thermal capacitance $C = 6Joule/°C$, under a power pulse $P = 10W$ ($10A \times 1V$), would experience a temperature rise, given enough time, by a clearly unacceptable amount $\Delta T = R \times P = 50 \times 10 = 500°C$. However, if the power pulse is limited in time, for example $t = 60s$, then the temperature rise is damped by the effect of the RC constant, and is limited to a more acceptable $\Delta T \approx t \times P/C = 60 \times 10/6 = 100°C$. The linear approximation for ΔT is valid for $t < RC$ and $e^{-t/RC} << 1$. This example shows the importance of managing power dynamically, rather than statically, by understanding and controlling the system power profile over time in relation to its thermal constants.

The Efficiency Challenge

Accordingly, a switching regulator IC with a thermal resistance $R' = 60°C/W$ and a thermal capacitance $C' = 4Joule/°C$, delivering a 10W power pulse at efficiency $\eta = 85\%$, will dissipate the power $P' = (1-\eta) \times P = 0.15 \times 10 = 1.5W$. Assuming all the losses can be attributed to the IC, given sufficient time, its temperature would rise to $\Delta T' = R' \times P' = 60 \times 1.5 = 90°C$ above the ambient temperature. However, after 60s, the temperature would rise only by $\Delta T' \approx t \times P'/C' = 60 \times 1.5/4 = 22.5°C$.

Naturally, the higher the efficiency, the lower the losses the voltage regulator will incur and the lower the temperature rise.

The Power of Accuracy

A voltage regulator delivering 0.9V output with ±1% accuracy to a resistive load Rr at +1% error will deliver 2% excess power (V^2/Rr). That is the same as taking the efficiency curve and lowering it by 2% points! Accuracy saves power.

The Power of Fast Transient Response

The output of a slow voltage regulator will dip under a positive transient load and will need to be positioned higher to assure that the load receives the minimum voltage necessary to operate. Similar considerations are valid for a regulator that exhibits high voltage ripple. In both cases, this results in wasted power and greater heat generation, ultimately ending in less battery life. Fast transient response and low ripple save power.

The Size Challenge

As discussed earlier, a large amount of power must be packed into the small volume of a smartphone. Accordingly, the buck converter must be accurate, fast, and efficient to minimize power losses. Efficiency must also be maintained while operating with high clock rates to reduce the size of the passive components (output inductors and input and output capacitors).

Quad-Phase Buck Converter

The MAX77874 16A, quad-phase, buck regulator (Figure 2) successfully manages the challenges outlined above. Dividing the current between four phases that are equally spaced in time across one clock period has several advantages compared to a single-phase architecture.

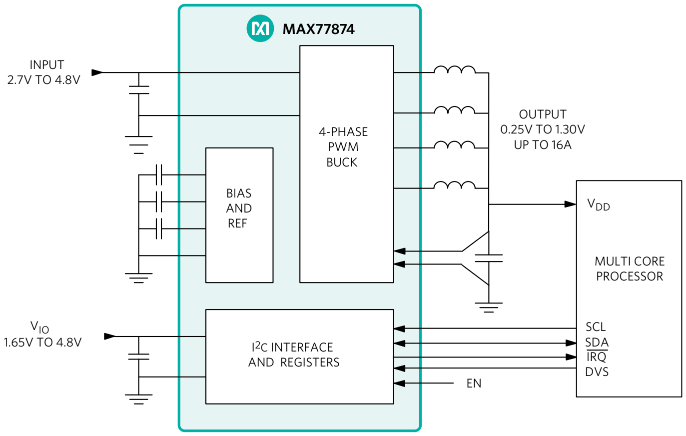

Figure 2. MAX77874 Quad-Phase Block Diagram

First, the four interleaved phases assure ripple current cancellation as shown in Figure 3. Low total ripple current is obtained at a relatively low per-phase frequency of operation. Lower ripple current means fewer capacitors are needed on the output, resulting in a smaller BOM.

Second, the multiphase architecture results in the need for fewer input capacitors. Figure 4 shows the V_{LXA}-to-V_{LXD} voltage waveforms applied to the inductors in forced PWM mode. This can also be viewed as a representation of the pulses of current drawn at the input by each inductor during the 'on' time. The total input current is the sum of the four out-of-phase currents. Here, spreading the total input current over time reduces the input current total RMS value, compared to single-phase operation, allowing for a smaller input current ripple filter.

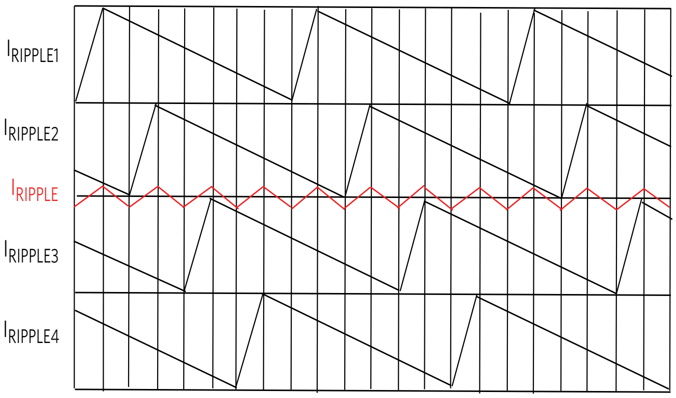

Figure 3. Quad-Phase Output Current Ripple Cancellation

Third, a multiphase scheme is more efficient than a single-phase scheme. The latter, by running at 4 times the frequency of the quad phase, can also achieve low ripple but at higher switching losses. The two schemes have an equal number of transitions within one period but the quad-phase converter transitions carry a quarter of the current of the single-phase converter.

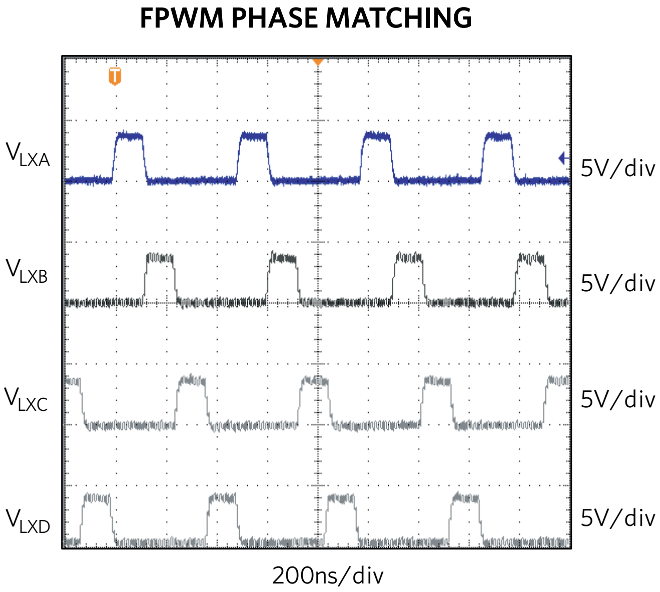

Figure 4. Quad-Phase LX Voltage Waveforms

MAX77874 Enhanced Features

The MAX77874 features an adaptive on-time control loop, which is an enhanced version of the popular, fast-response, constant on-time control. The adaptive scheme results in pseudo-constant frequency in a scheme that otherwise would have variable frequency, which can be problematic in noise-sensitive applications. This mode of operation is also known as forced PWM (FPWM) mode. The compact 48-bump, 0.35mm pitch WLP array package of the MAX77874 also requires minimal PCB area.

Enhanced Transient Response

During a heavy load transient, the four phases move from interleaved to parallel operation. Paralleling the four phases results in the fastest possible load current step response since the four inductor currents are concurrently delivered to the load. In Figure 5, the buck converter operates in FPWM mode at any load and during the transition from light to heavy load.

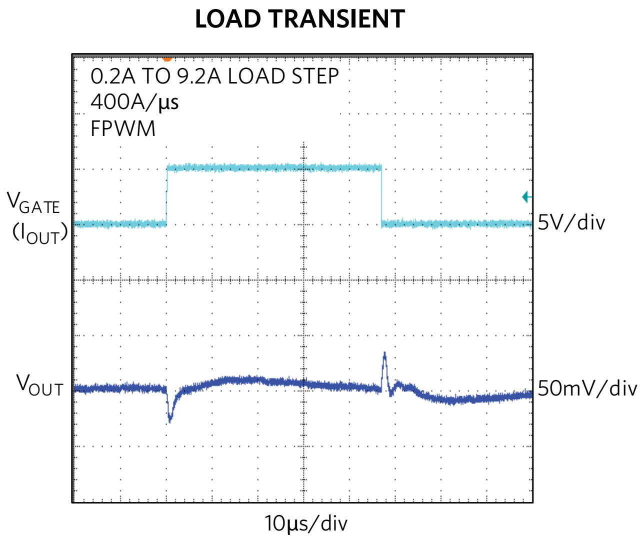

Figure 5. FPWM Transient Response

Turbo Skip Mode

Turbo skip mode combines superior transient response with light-load efficiency. At light loads and when enabled, the MAX77874 turbo skip mode (Figure 6) keeps all four phases operating sequentially but at a lower quiescent current and variable frequency. This is known as rotational phase spreading.

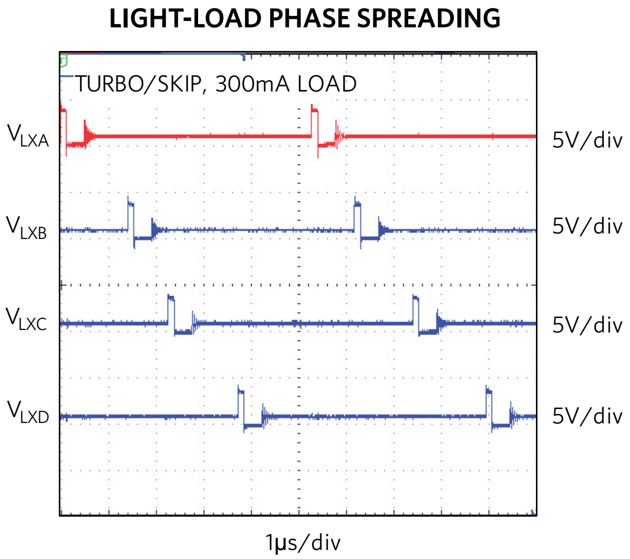

Figure 6. Light-Load Rotational Phase Spreading

This way, during a transition from light to heavy loads, there is no delay in activating all four phases and the MAX77874 performs as well as it does in FPWM mode (shown by comparing Figure 5 with Figure 7).

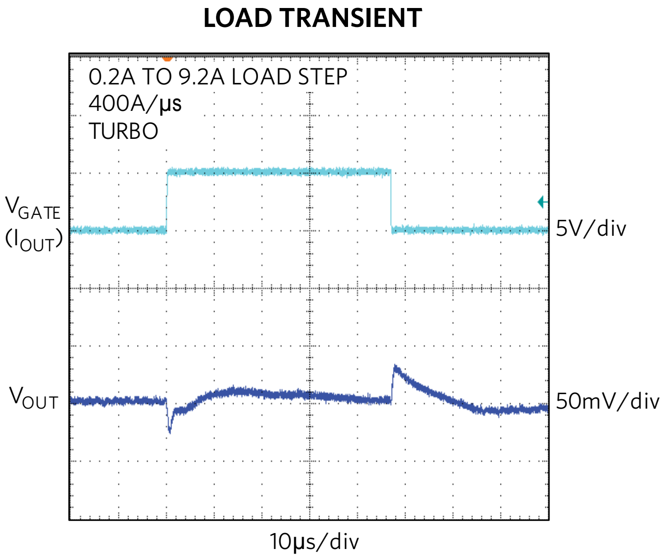

Figure 7. Turbo Skip Mode Transient Response

Compared to phase shedding–turning off some of the four phases at light loads–this scheme produces less output ripple and has fewer glitches. Figure 8 shows that with rotational phase spreading, the output voltage ripple is less than $3mV_{P-P}$ from 0 to 500mA. The turbo skip mode is the default mode of operation at light loads.

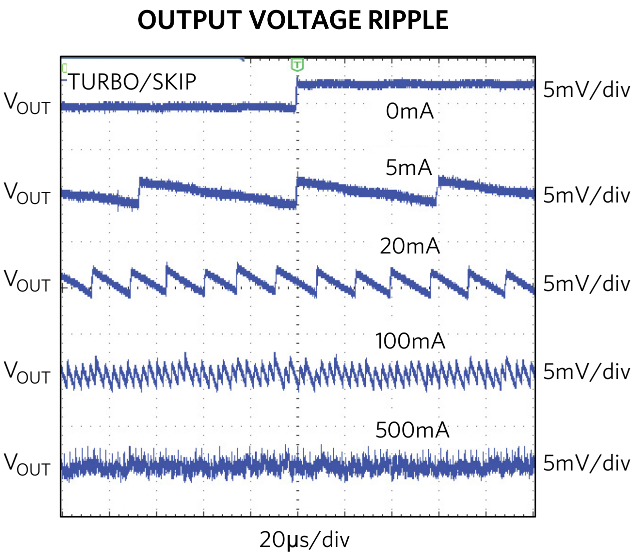

Figure 8. Output Voltage Ripple with Phase Spreading

Skip Mode

Regular skip mode provides the lowest supply current and highest efficiency at light loads, although with slightly slower response. The modes of operation can be programmed through the I^2C bus.

The Accuracy Advantage

With an initial output accuracy of ±2.5mV (±0.25% at 1V output) and outstanding performance over temperature, line, and load regulation, the MAX77874 has the best output accuracy. Figure 9 shows the initial output accuracy vs. the setting in Skip, Turbo Skip and FPWM modes.

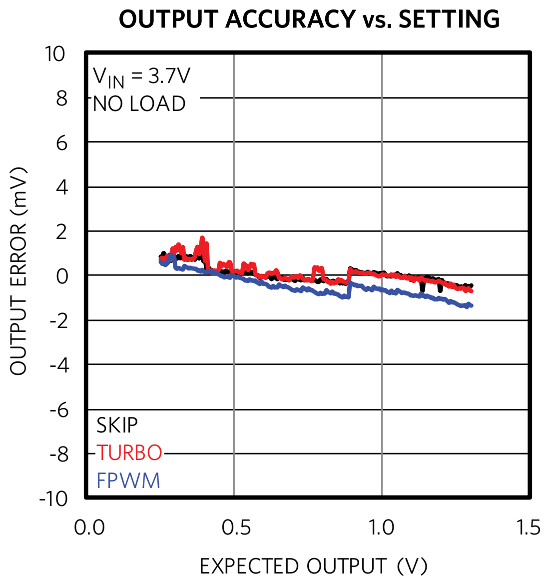

Figure 9. Output Voltage Initial Accuracy vs. Setting

The Efficiency Advantage

The enhanced features of the MAX77874 integrated power MOSFETs result in superior efficiency compared to competitive quad-phase solutions. The efficiency comparison in Figure 10 shows that the MAX77874, even with a smaller 2012 inductor, has an advantage of up to 4% versus a competitive device.

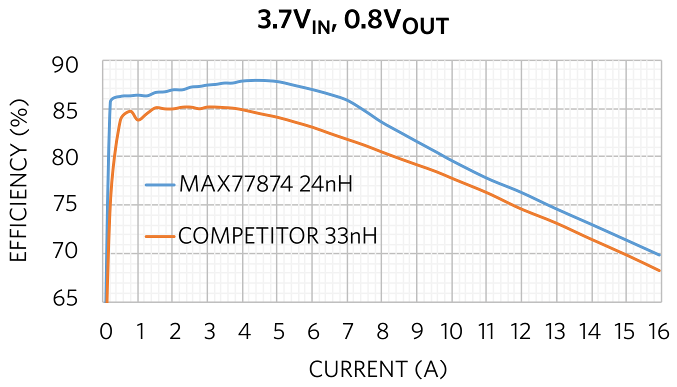

Figure 10. Efficiency Comparison

The Size Advantage

The MAX77874 application requires only a small 37mm^2 area when placed on a PCB (Figure 11), an overall 29% size advantage compared to a competitive solution.

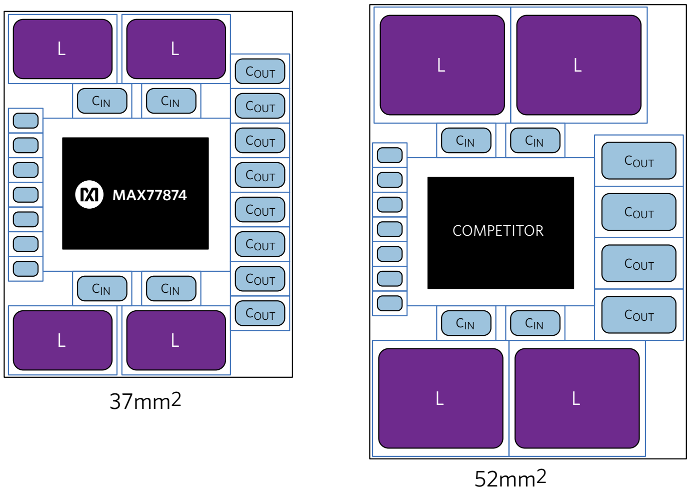

Figure 11. MAX77874 Size Advantage

Conclusion

We have discussed the growing trend of smartphones using increasingly powerful CPUs and GPUs (graphics processing units) and the implications of dynamic power management and heat dissipation. We presented a solution based on the MAX77874 that improves state-of-the-art quad-phase buck converters and delivers best-in-class efficiency and size advantages.

Learn more:

MAX77874 16A High-Performance Quad Phase Buck Regulator for Multicore CPU and GPU Processors

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