APPLICATION NOTE 6855

How to Select the Right Front-End Buck Converter for Your Automotive ECU

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Abstract: Internal combustion engine (ICE) vehicles rely on a lead-acid battery to supply their numerous electronic control units (ECUs) required by the introduction of advanced driver assistance systems (ADAS). Depending on system complexity, these loads require from a few amperes to tens of amperes of current. In this application note, we review different levels of complexity for an automotive ECU power management system. For a low level of complexity, a monolithic front-end buck converter is the best solution for efficiency and PCB size. For medium levels of complexity, a PWM controller, in conjunction with external MOSFETs, is the best approach. Finally, for higher level of power, a two-phase interleaved approach yields the best results in terms of efficiency and size.

The introduction of advanced driver assistance systems (ADAS) in automobiles has increased the number of electronic loads through the addition of multiple displays and sensors. High-end automobiles require close to one hundred electronic control units (ECUs). Each ECU draws power from the car battery through a buck converter. The system-on-chip (SoC) in ECUs require increasingly higher levels of power—in some cases close to 200W.

Internal combustion engine (ICE) vehicles rely on a lead-acid battery to supply the power to the electronic loads (**Figure 1**). The interface between the battery raw power and the delicate electronics requires a front-end regulator that can support different transient conditions, such as cold crank and start/stop, while withstanding load dump. The front-end regulator in turn must deliver a clean intermediate voltage that can be converted up or down to provide the specialized rails required by each electronic load.

In this article, we review the power management requirements for ECUs with different levels of complexity and explain how to select the optimal front-end regulator solution for each.

Figure 1. The Lead-Acid Battery Powers the ICE Car Electronics

Typical ECU System

Figure 2 illustrates a typical ECU automobile power management environment. A front-end buck converter interfaces with the battery, handling its voltage variability and transients (load dump), and delivers a nicely controlled voltage of 3.3V. From this rail, the major elements of the automobile electronics are powered. The front-end buck's total current load can vary from a few amperes to tens of amperes, depending on system complexity.

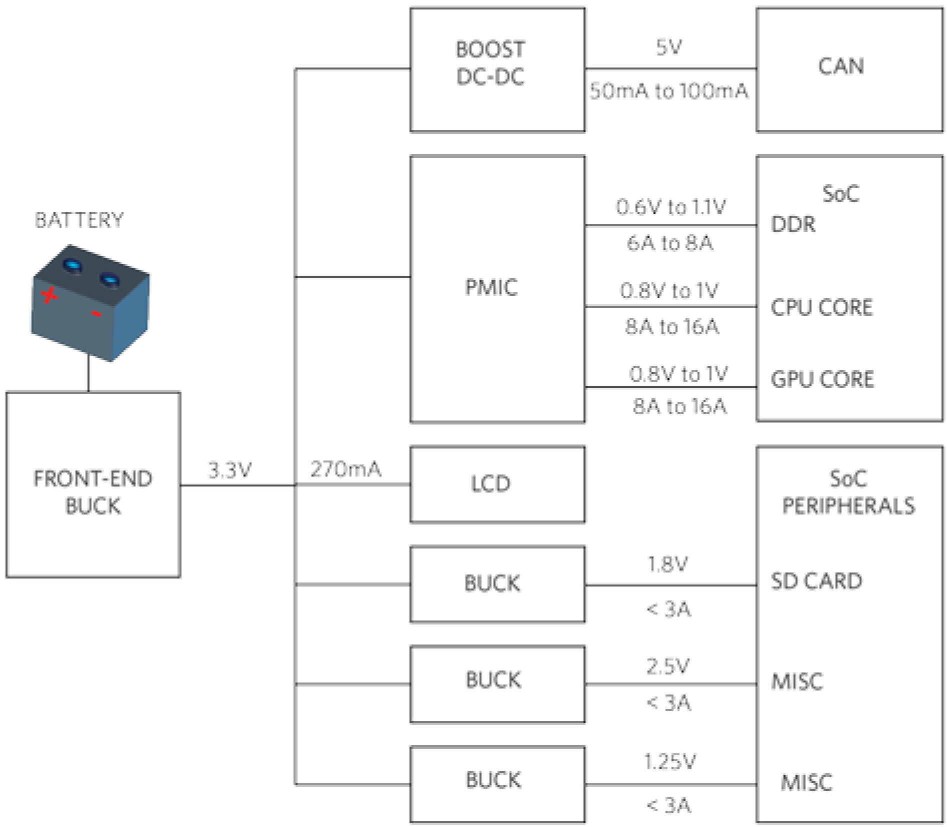

Figure 2. ECU Power Management System

The buck converter must withstand the battery voltage, which can be as high as 14.7V on a fully charged battery. Vehicles employing start-stop technology experience large voltage dips when the engine starts, so the lower limit for the power source is well below the typical 12V and can be as low as 4V or lower. A high and well-controlled PWM switching frequency (above the AM band range of 500kHz to 1.7MHz) is required to reduce radio frequency interference while spread spectrum is necessary to meet electromagnetic interference (EMI) standards. With only 100µA of quiescent current at the ECU's disposal, every microamp spared by the on-board buck converter is one more microamp that is usable for the module's microcontroller, memory, or controller area network (CAN). Finally, a high-efficiency buck converter will reduce total heat generation, improving the system's reliability.

Low Level of Complexity

If the ECU level of complexity is low, a simple, fully monolithic IC will suffice for the front-end buck converter as shown in **Figure 3**. For current levels below 8A, a monolithic solution can deliver the best efficiency in the smallest possible PCB area. Monolithic converters integrate the MOSFETs, which allows clean and effective sensing of the inductor current across the high-side MOSFET $R_{DS(ON)}$, avoiding the use of a costly and dissipative sense resistor. Integration of the MOSFETs also reduces the overall solution size and cost while minimizing the parasitics introduced by the PCB layout. An optimal layout improves the EMI performance and increases efficiency.

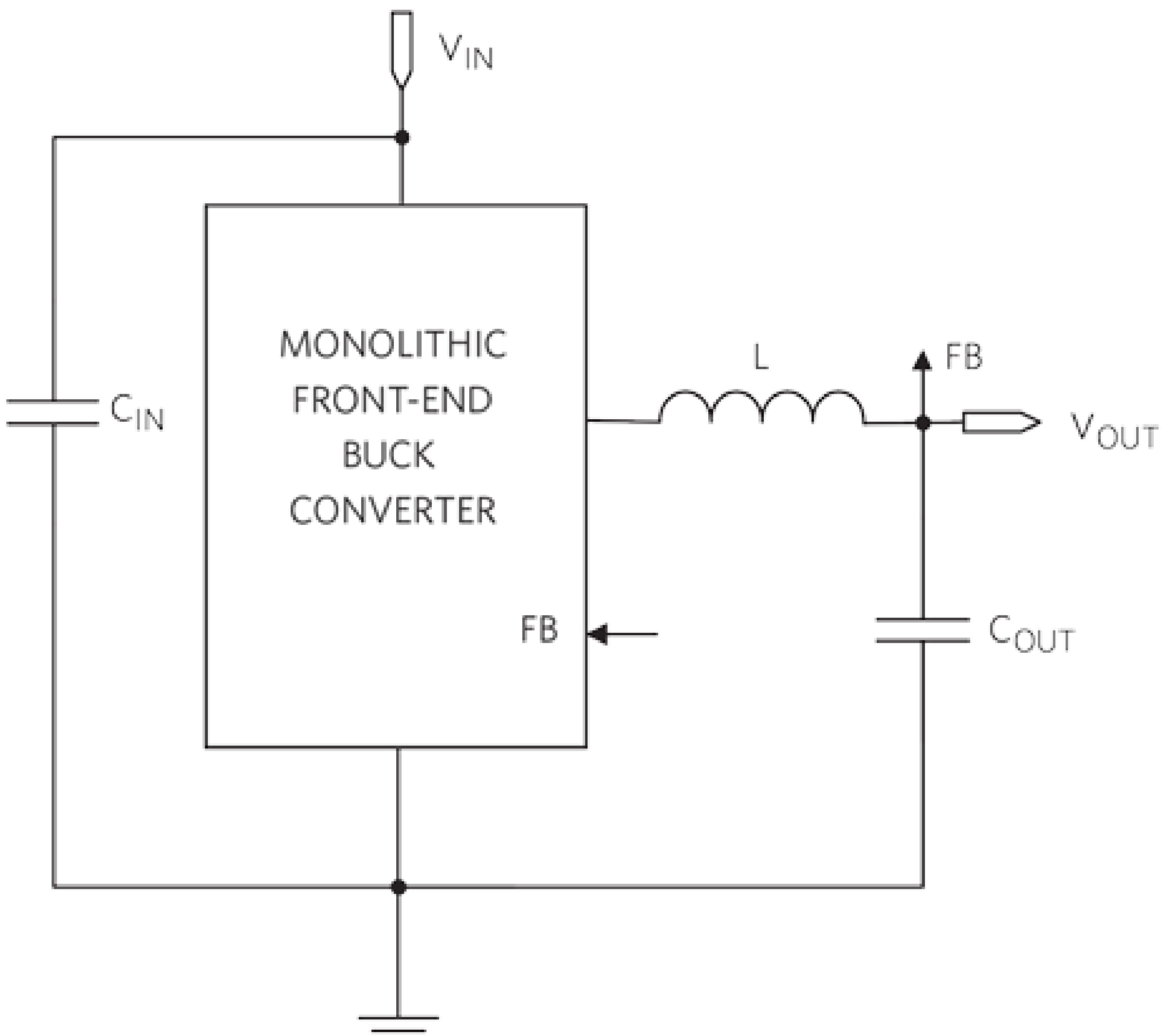

Figure 3. Monolithic Front-End Buck converter

With this implementation, the total PCB area of a 3.3V, 6A solution is 300mm^2 as shown in **Figure 4**.

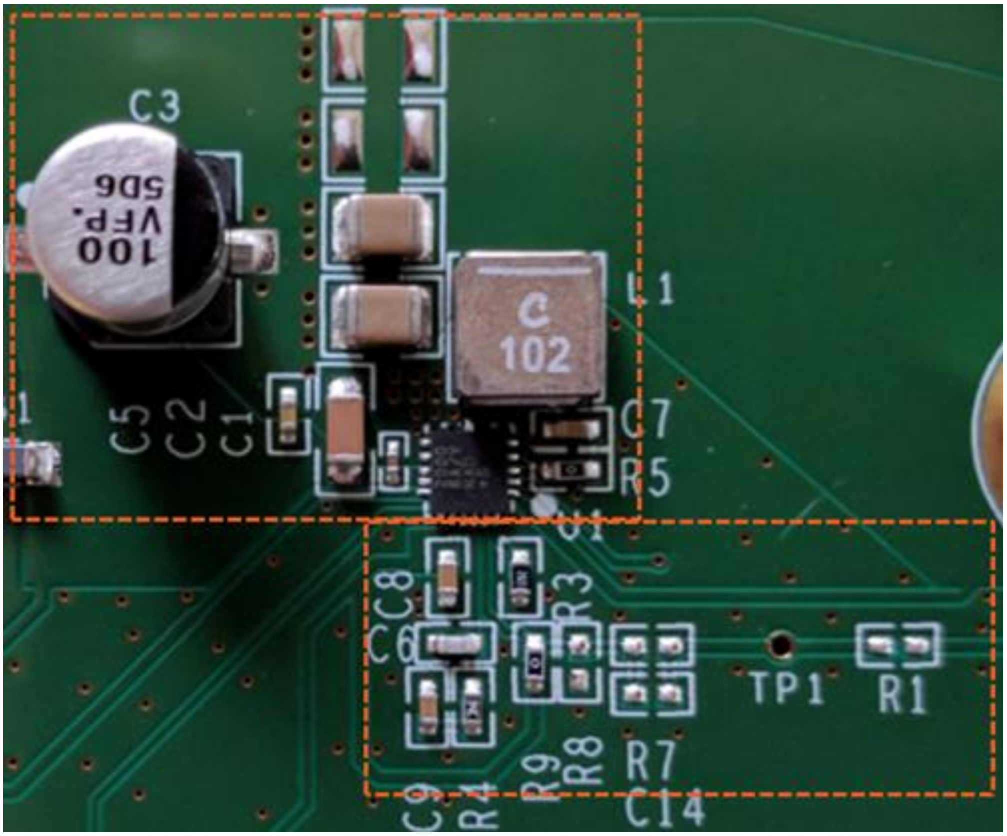

Figure 4. Monolithic Front-End Buck Converter PCB Area (300mm^2)

Medium Level of Complexity

For medium-to-high level system complexity, requiring 8A to 20A of total current, the most convenient solution for the front-end buck converter is a controller IC and external low-$R_{DS(ON)}$ MOSFETs (**Figure 5**). High efficiency is obtained by proper selection of the MOSFETs, inductor, and optimum PCB layout. Further reduction in losses is achieved by direct current resistance (DCR) current sensing, which avoids the losses associated with a sense resistor. In this case, the inductor current is sensed across the C_S capacitor. If the inductor time constant (L/R_L) is matched to the external network's time constant (R_S x C_S), the voltage across the capacitor C_S equals the voltage across the inductor parasitic resistance R_L (of known value). This allows the derivation of the inductor current.

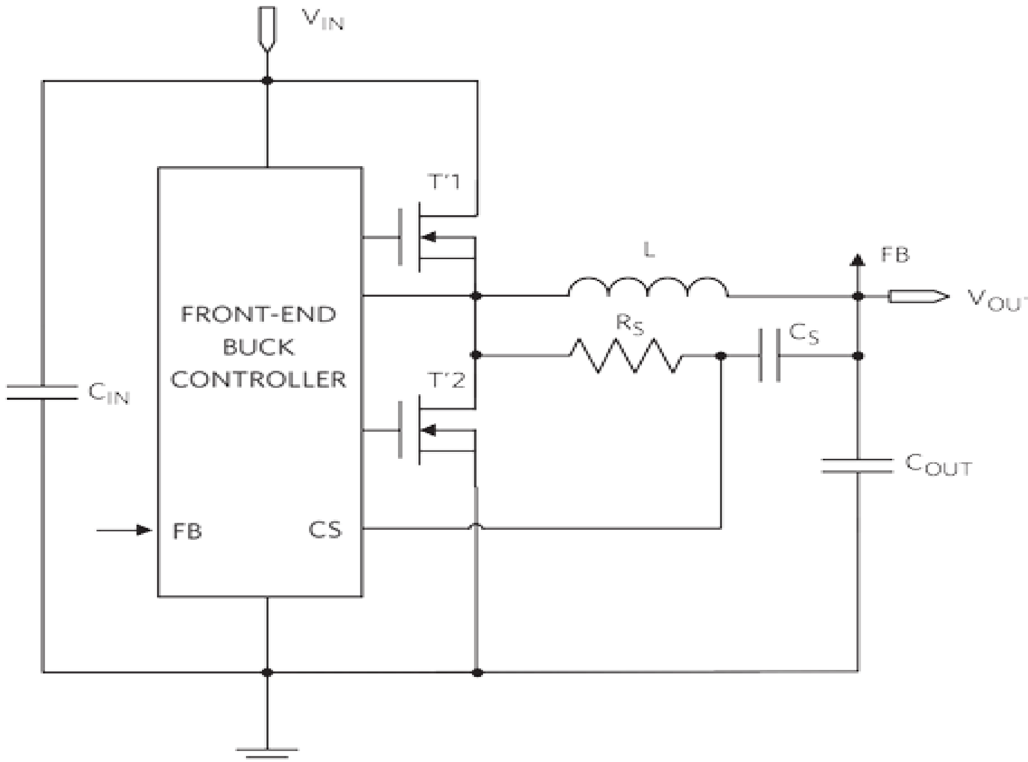

Figure 5. Front-End Buck Controller with External MOSFETs

With this implementation, the PCB area of a 3.3V, 7A solution, is 500mm^2 as shown in **Figure 6**. The quasi-apple-to-apple comparison between this and the previous case show the advantages of using a monolithic solution for systems with total current levels below 8A. On the other hand, the controller-based solution becomes mandatory at higher currents.

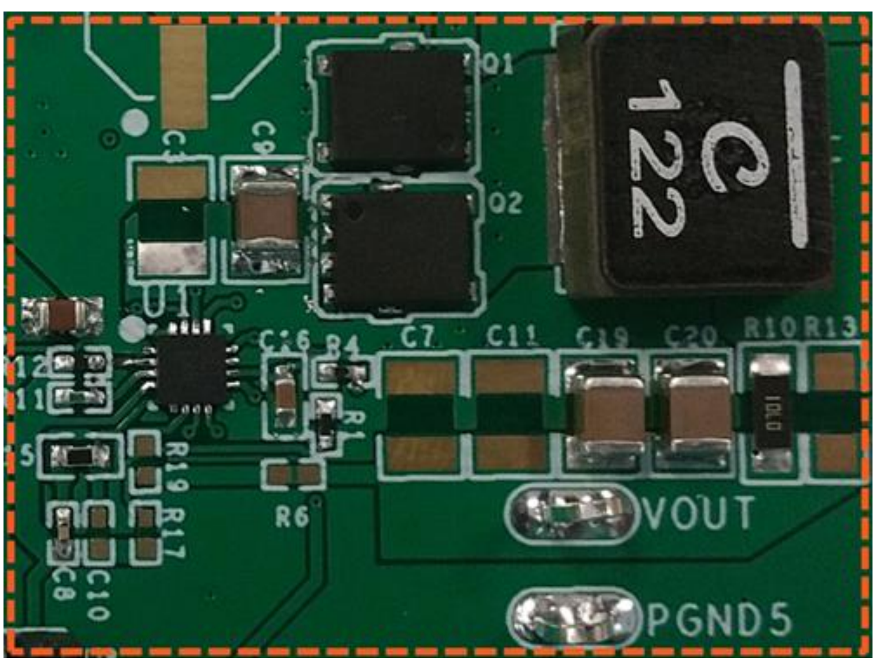

Figure 6. Controller Based Front-End Buck PCB Area (500mm^2)

High Level of Complexity

For systems that require a total current level above 20A, a two-phase interleaved controller is the best solution for the front-end buck converter as shown in **Figure 7**

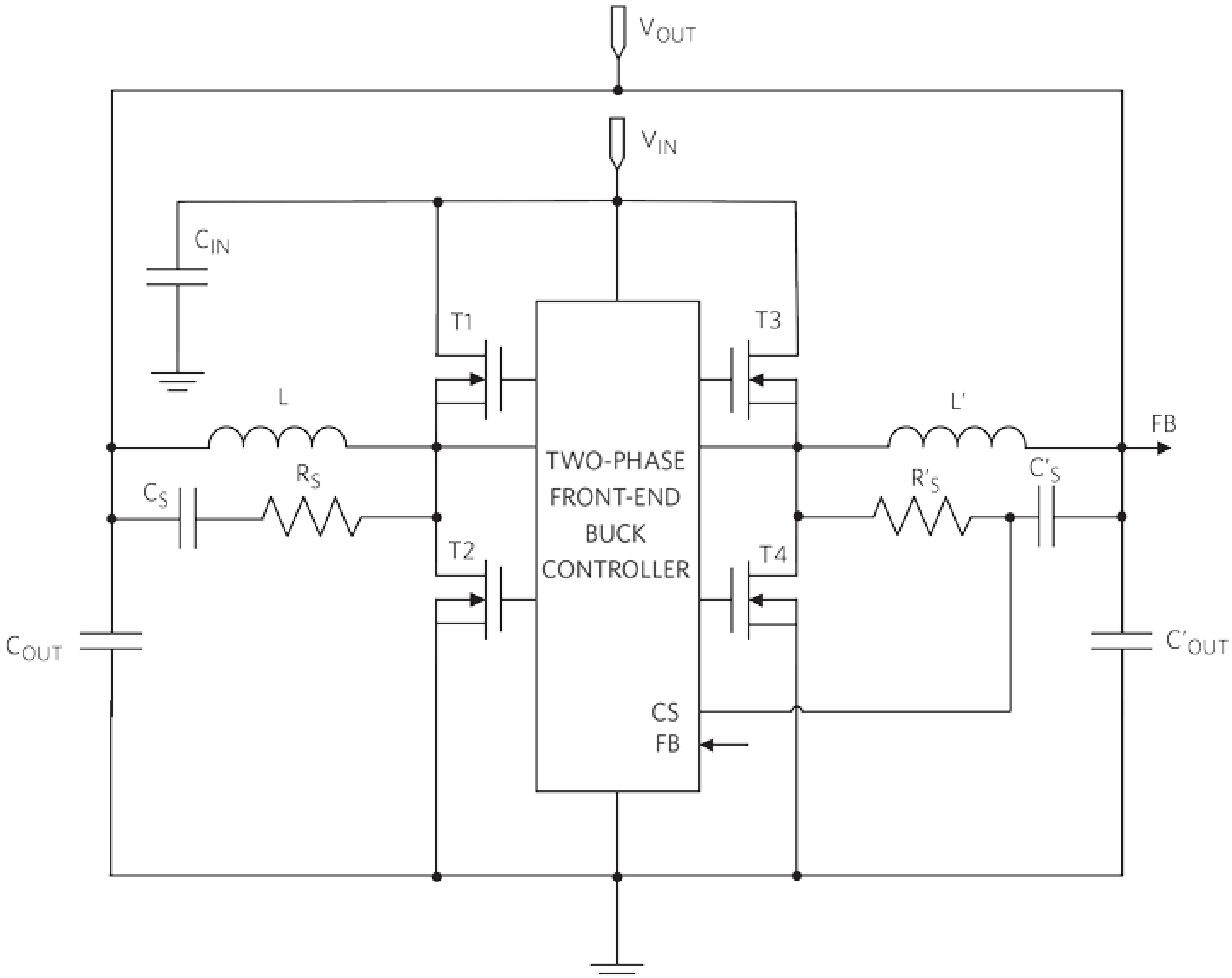

Figure 7. Two-Phase Interleaved Front-End Buck Converter

The two interleaved phases assure ripple current reduction. Low total ripple current is obtained at a relatively low per-phase frequency of operation. As an example, **Figure 8** shows that two ripple currents 180° out-of-phase at 33% duty cycle result in a total ripple current with half the amplitude of a single phase at twice the frequency. Lower ripple current at higher frequency means fewer capacitors are needed on the output, resulting in a smaller BOM.

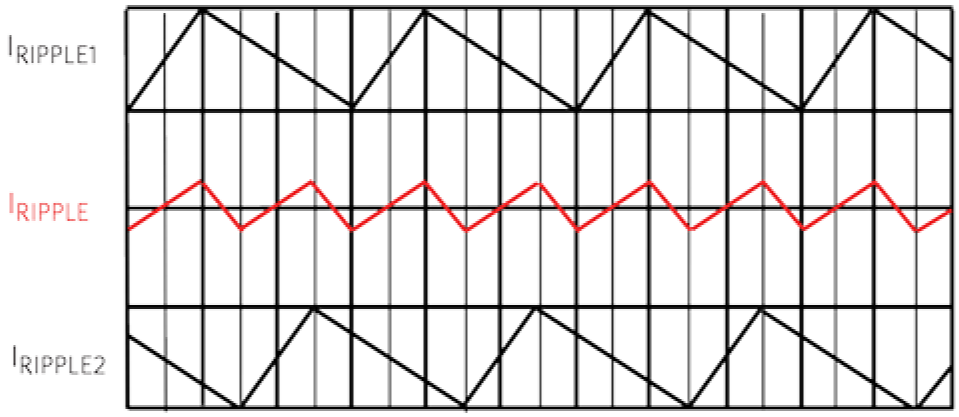

Figure 8. Two-Phase Current Ripple Reduction vs. Time

The two-phase architecture also requires fewer input capacitors. The total input current is the sum of the two out-of-phase currents (I_{IN1} and I_{IN2} in **Figure 9**). Here, spreading the total input current over time reduces the input current's total RMS value, compared to a single-phase operation that allows for a smaller input current ripple filter.

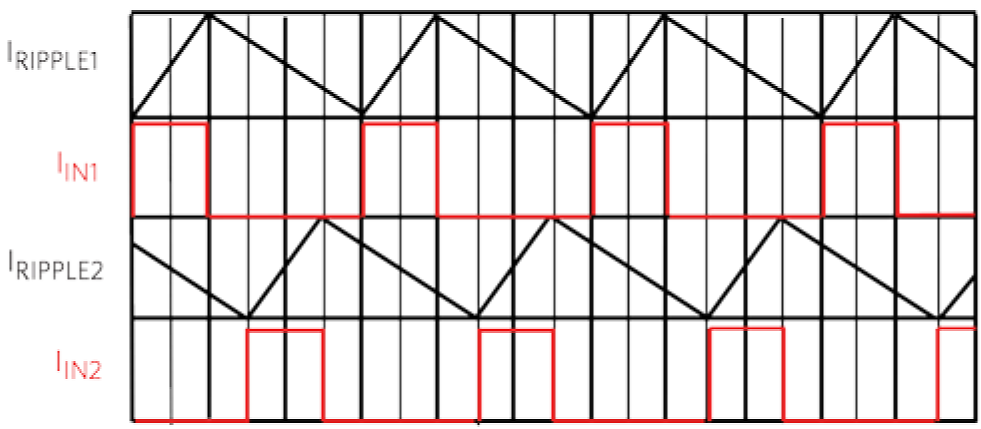

Figure 9. Two-Phase Output Ripple Currents and Input Currents vs. Time

Additionally, as shown in **Figure 10**, two-phase (2Φ, shown in red) is more efficient than single-phase (1Φ, shown in blue) when the two schemes run at the same output ripple frequency. Single-phase, by running at two times the clock frequency (f_{CK}) of two-phase, can also achieve high frequency and low current ripple but at higher switching losses. The two schemes have an equal number of transitions within one period, but the dual-phase converter draws half the current of the single-phase converter (over twice the duration), thus reducing the switching losses.

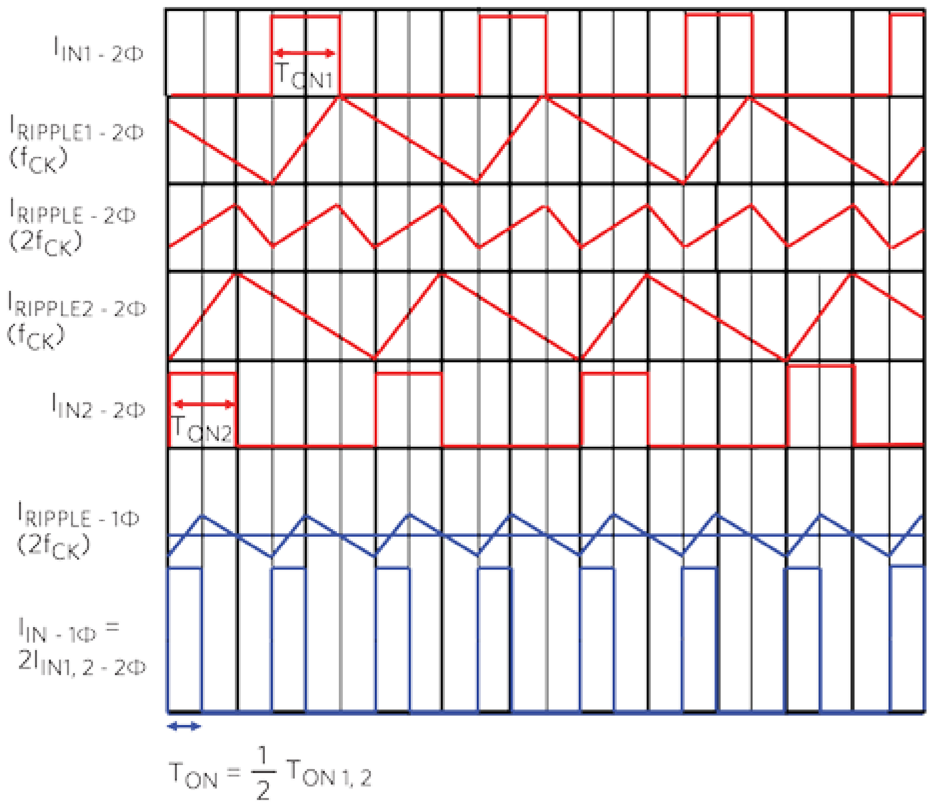

Figure 10. Two-Phase vs. Single-Phase Currents vs. Time

Another great benefit of a dual-phase converter is the fast-transient response and reduced voltage overshoot/undershoot during load steps. With half the current per phase, reduced current ripple amplitude, and double the ripple frequency, the phase switching frequency can now be pushedhigher to reduce the component size further and increase the close-bandwidth of the converter without running into thermal limitations.

Finally, as the total load current increases, the size of the passive components increases. For loads above 20A, the external FETs and inductor for a single phase can be bulky and inefficient. Having a multiphase operation reduces the current in each phase, which ensures optimal sizing for passives.

Solution Example: Low Complexity System

The MAX20004, MAX20006, and MAX20008 are small, synchronous buck converters with integrated high-side and low-side MOSFETs. They deliver up to 8A with input voltages from 3.5V to 36V, while using only 25µA quiescent current at no load. The small 3.5mm x 3.75mm package requires minimal board space and very few external components.

EMI is the number one concern for automotive customers. Forced pulse-width-modulation (PWM) mode is available to eliminate frequency variation and help minimize EMI. Factory-enabled spread spectrum is also available for further EMI reduction. **Figure 11** shows devices that comfortably meet the limits for radiated emissions.

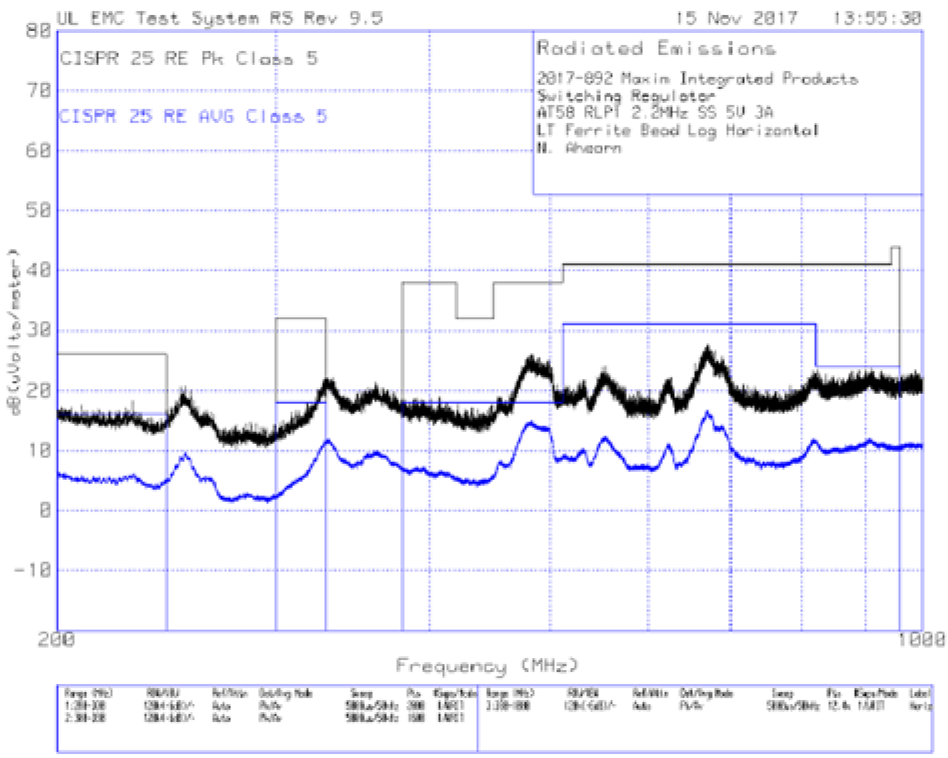

Figure 11. Low Radiated Emission with FPWM and Spread Spectrum

Figure 12 shows the MAX20006 buck converter's efficiency advantage versus a similar device. Low-$R_{DS(ON)}$ integrated MOSFET transistors and an FCQFN package without bond wires assure superior efficiency at high load current.

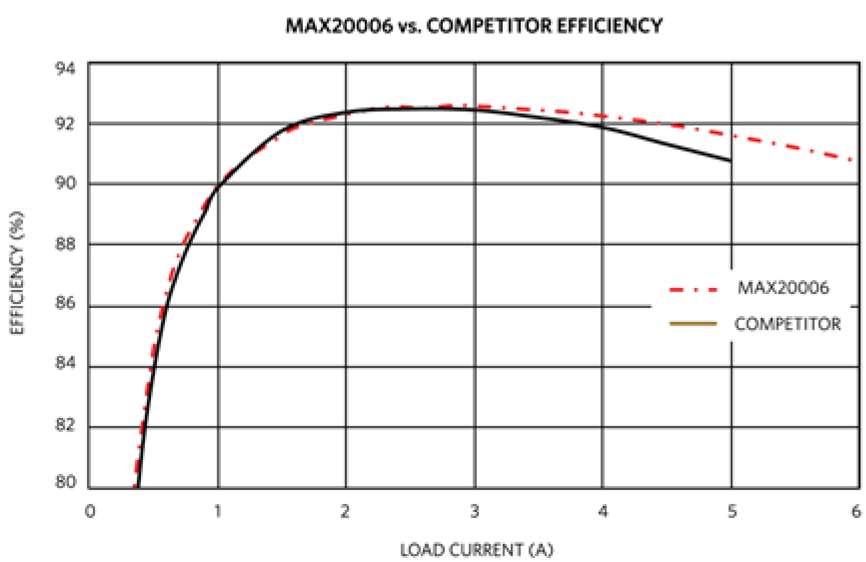

Figure 12. Buck Converter Efficiency Comparison

Solution Example: Medium Complexity System

The MAX20098 is a 2.2MHz synchronous step-down controller IC with 3.5µA quiescent current. This device operates with an input-voltage supply from 3.5V to 42V and can operate in dropout condition by running at 99% duty cycle. It is intended for applications with mid- to high-power requirements and currents up to 20A. For highest efficiency, the device's clock frequency can be adjusted down to 220kHz.

Solution Example: High Complexity System

The MAX20034 is a 2.2MHz, single-output, two-phase interleaved or dual-output, single-phase synchro¬nous step-down controller. The device operates from a 3.5V to 42V input-voltage supply and can function in dropout condition by running at 99% duty cycle. It is intended for applications with high-power requirements and currents up to 40A. For highest efficiency, the device's clock frequency can be adjusted down to 220kHz.

All the example devices support applications that require power conditioning directly off the car battery. These are characterized by a wide-input voltage range, to help survive severe transient conditions such as automotive cold-crank or engine stop-start conditions.

Conclusion

ICE-powered vehicles rely on a lead-acid battery to supply their numerous electronic loads. Depending on system complexity, these loads require from a few amperes to tens of amperes of current.

In this article, we reviewed different levels of complexity for an automotive ECU power management system. For a low level of complexity, a monolithic front-end buck converter is the best solution for efficiency and PCB size. For medium levels of complexity, a PWM controller, in conjunction with external MOSFETs, is the best approach. Finally, for higher level of power, a two-phase interleaved approach yields the best results in terms of efficiency and size.

Glossary

ADAS: Advanced driver assistance systems
ECU: Electronic control unit

Related Parts		
MAX20004	36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Automotive Step-Down Converters	Samples
MAX20006	36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Automotive Step-Down Converters	Samples
MAX20008	36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Automotive Step-Down Converters	Samples
MAX20034	High-Efficiency 2.2MHz, 36V, Dual Buck Controller with 17µA Quiescent Current	Samples
MAX20098	Versatile Automotive 36V 2.2MHz Buck Controller with 3.5µA I_Q	Samples

Review Featured Products

- MAX20004: 36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Step-Down Converters
- MAX20006: 36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Step-Down Converters
- MAX20008: 36V, 220kHz to 2.2MHz, 4A/6A/8A Fully Integrated Step-Down Converters
- MAX20034: High-Efficiency 2.2MHz, 36V, Dual Buck Controller with 17µA Quiescent Current
- MAX20098: Versatile 36V 2.2MHz Buck Controller with 3.5µA I_Q