

POWER MANAGEMENT FOR ADVANCED DRIVER ASSISTANCE SYSTEMS

Design Guide

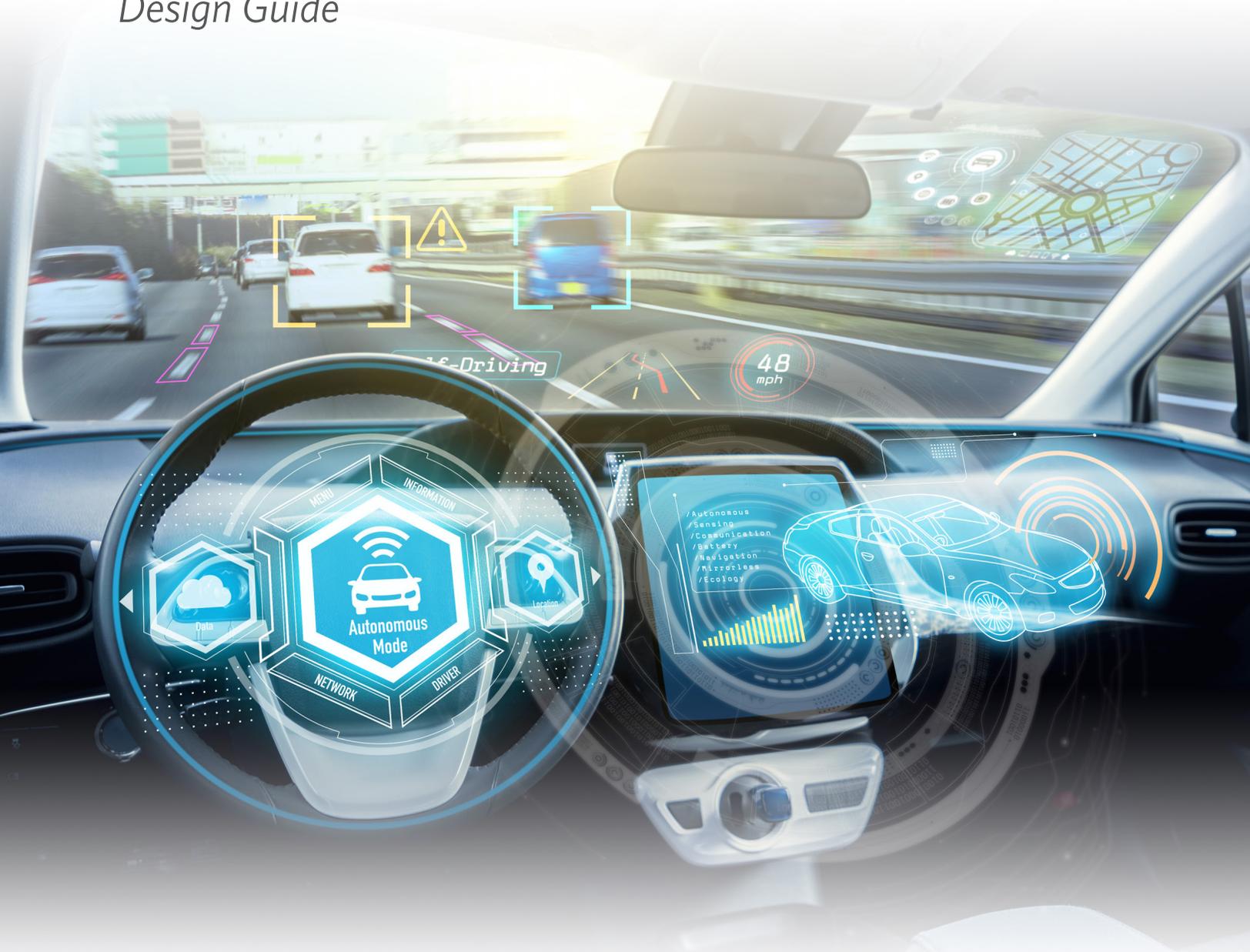
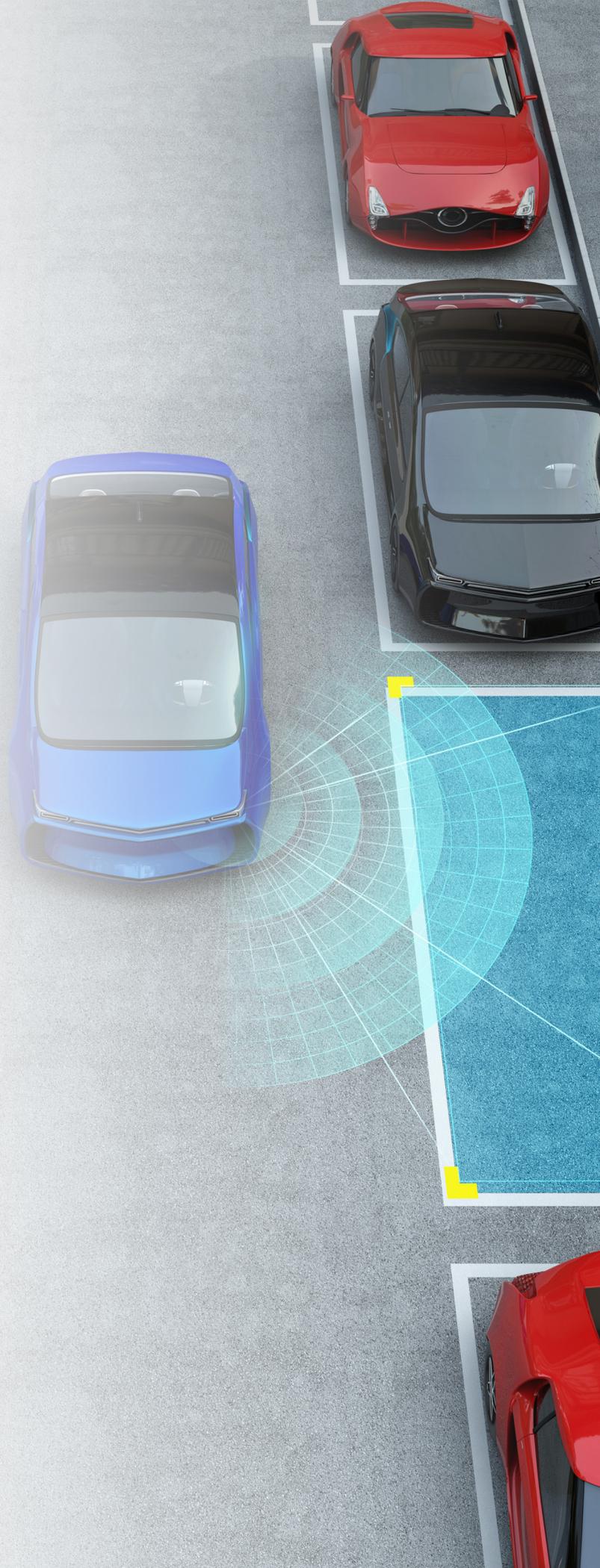


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Introduction

The field of solutions for automotive Advanced Driver Assistance Systems (ADAS) is rapidly growing. Autonomous emergency-braking systems and forward-collision warning systems will soon be mandatory in the United States and Europe. The list of ADAS features is extensive and includes driver monitoring systems (DMS) to monitor a driver's attention level (**Figure 1**), autonomous driving, adaptive front lighting control, automatic parking, traffic sign recognition and more.

New ADAS technologies have the potential to improve driver safety and comfort, and even more importantly, to reduce automobile accidents and casualties. However, the adoption of ADAS technologies introduces new issues for automotive design especially in electronic solution size, safety, and reliability. This design guide reviews the megatrends underlying ADAS and its associated technological challenges. It then examines new solutions to address these challenges in power management through several case studies.



Figure 1. ADAS in Action

Megatrends in ADAS

ADAS is a key disruptive technology ushering in a new age of smart mobility in transportation. Automakers increasingly see themselves as both product manufacturers and mobility service companies. In addition to developing next-generation connected and autonomous vehicles that will improve traffic flow and safety, automakers are investing in a wide swath of new mobility services. Urban planners will use the mobility ecosystem to reduce congestion, while generating related benefits such as fewer traffic accidents, better air quality, and a smaller urban footprint for parking. ADAS, with its emphasis on safety, is even expected to disrupt the automobile insurance industry to the benefit of consumers.

ADAS capabilities are enabled by a plethora of sensors deployed across the car which are networked to I/O modules, actuators, and controllers throughout the automobile. Ultimately, the on-board sensors connected to cloud support functions will provide external data from other vehicles and from cloud infrastructure for connected safety, advanced driver assistance support, and autonomous driving software and functions.

Technology Enablers

All this additional intelligence, networking, and control is enabled by phenomenal advances in sensing, connectivity, processing, and cloud computing. These technologies crystallize in the electronic control unit (ECU), at the center of the car electronics architecture. High-end cars require close to a hundred ECUs, each taking power from the car battery with the intermediation of an on-board buck converter (*Figure 2*). Each ECU is dedicated to a specific function and incorporates power regulation, a processing unit (MCU), and the means to receive data from sensors, drive actuators, and display information.

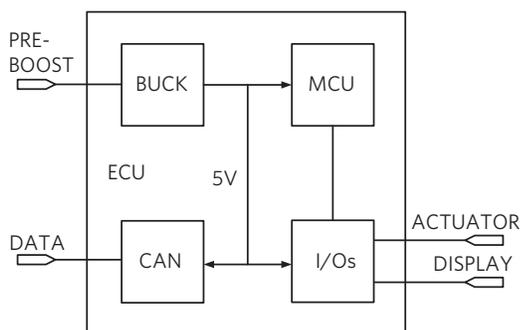


Figure 2. ECU Block Diagram

Challenges

The proliferation of ADAS functions requires a large number of processors and connectivity interfaces in every controller, sensor, I/O, and actuator in the car. This, in turn, places new requirements on system hardware including: reduced component size to fit additional electronics in the same space, improved energy efficiency to perform within the same or lower thermal budget and increased electrical/mechanical safety and reliability to reduce failures.

The ECU's power management electronics must withstand harsh automotive environments (cold/hot crank, load dump, start/stop), have high accuracy, be well protected (short to ground, short to battery, OV, OC, etc.) and be protected from electromagnetic interference (EMI). This is true for both "safety" modules such as the radar module, sensor fusion and controller area network (CAN as well as for non-safety modules such as infotainment, clusters, and head units). Additionally, safety modules must conform to Automotive Safety Integrity Level (ASIL) standards, including tighter protections and accuracy, redundant references, fail-safe on open pins and other diagnostics. Accordingly, many power management products are offered in both ASIL and non-ASIL versions.

In summary, the primary challenges for the electronic components are:

1. Miniaturization
2. Safety and Reliability

Challenge 1 - Miniaturization

In this section, we discuss space-saving power management solutions for the automobile. First, we will discuss remote cameras located along the automobile periphery, then move on to the ECUs at the heart of the smart car. Finally, we will review the front-end voltage regulators that interface the battery.

Case Study I: How to Miniaturize Your Automotive Remote Camera

The market for ADAS is one of the fastest growing for automotive electronics. Cameras are a key element of the ADAS sensor toolset (*Figure 3*). Installed in selected locations around the vehicle exterior, an increasing number of cameras are used to deliver a surround-view experience, giving drivers new and previously unobtainable exterior views. Numerous benefits range from monitoring blindspots when changing lanes on the highway and aiding with parallel parking, to automatic traffic sign recognition and pedestrian detection. Advanced cruise control and situation-aware collision avoidance systems are on the horizon. These remote camera modules, with their on-board power management systems, must be small, efficient, and cost-effective.

This case study discusses the shortcomings posed by a typical automotive remote camera power management implementation and presents a highly integrated solution that occupies a fraction of the PC board (PCB) space while preserving high levels of efficiency.



Figure 3. ADAS Surround-View Illustration

Powering the Remote Camera

The remote camera module is typically powered by a power-over-coax (POC) 8V rail and consumes approximately 1W or less (< 125mA). This rail is bucked down to power the on-board electronic loads, including the imager and the serializer (*Figure 4*). The camera operates in an on/off fashion; either on at full operation or completely off. For this reason, it is more cost-effective to select streamlined buck converter ICs designed for high efficiency at full load without extra silicon (or costs) devoted to enhancing light-load operation. In *Figure 4*, the passive components are omitted for simplicity.

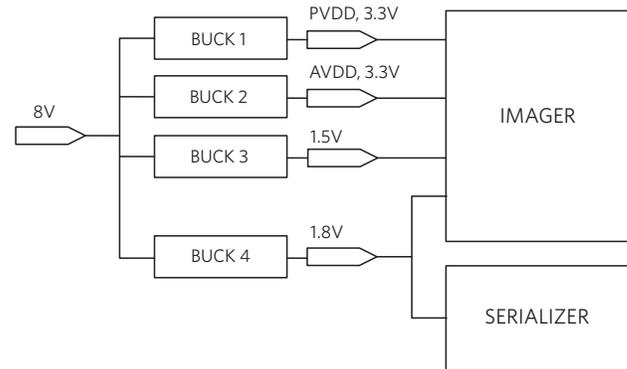


Figure 4. Remote Camera Power-Over-Coax Block Diagram

Typical Solution: Discrete Bucks

A typical solution implements each rail with a dedicated, 8V-powered, discrete buck converter. There are four converters usually designed around identical ICs for economies of scale and ease of design. However, since the buck converter loads are quite different, the overall design is inherently inefficient.

Reduced Efficiency

In this section, only two of the four rails (Buck 1 and Buck 4) are discussed in detail (*Figure 5*). Buck 2 and Buck 3 mirror the situation of Buck 1 and Buck 4 but are not discussed due to brevity.

The efficiency of Buck 1 with a 30mA load is suboptimal (78%) since it operates under a light load. The efficiency of Buck 4 is also suboptimal (82%) since it operates at a low duty cycle ($1.8V/8V = 0.225$). The net result is a system draw of 71mA from an 8V rail (568mW).

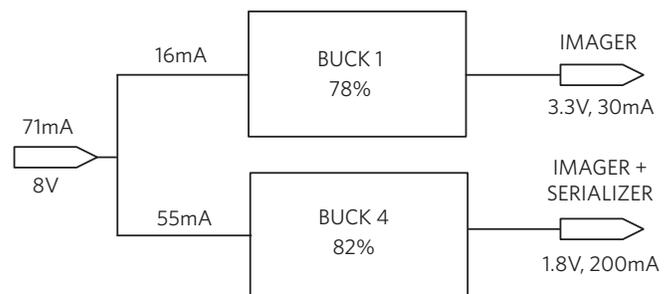


Figure 5. Discrete Buck Converters Power Two Rails

High Cost and Large Footprint

This discrete solution is costly and space-consuming, requiring one IC for each rail and the related passive components. As shown in Figure 6, the PCB space required by two of the four buck converters, including passives, is 160.4mm².

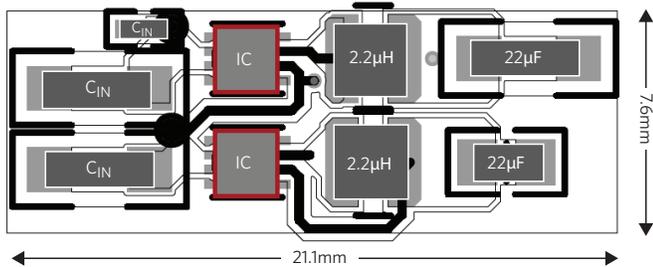


Figure 6. Footprint for the Two-Chip Solution:
21.1mm x 7.6mm = 160.4mm²

A Superior Solution: Dual-Buck Converter

By covering the four rails with two dual-buck converter ICs, we save additional space and preserve efficiency. Figure 7 shows the dual-buck solution for two of the four rails using the MAX20019. External passive components are omitted for simplicity.

Efficiency Preservation

Here, two integrated buck converters are optimized for cascaded operation, both working at or near full load and high duty cycle for the highest efficiency. The 1.8V buck converter, with only 3.3V at its input (as opposed to 8V in the typical architecture), is optimized for a mid-range duty cycle (1.8V/3.3V = 0.545) and operates at a 92% peak efficiency. The 3.3V buck converter is optimized for duty cycles from POC voltages of 8V (3.3V/8V = 0.412) to 12V and at near-full load, yielding a respectable 86% efficiency with 8V input. The net result is a draw of 71mA from the 8V rail, which demonstrates how this configuration preserves efficiency. More importantly, this solution reduces the bill of materials by using a single IC and smaller passives (more on this in the *Small Size* section).

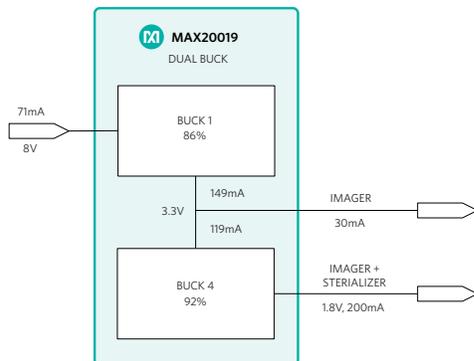


Figure 7. Single-Chip Solution for Two Rails

Small Size

Many enhancements contribute to the dual-buck solution size advantage. First, the integration of two buck converters into a single chip helps reduce the PCB footprint by eliminating one IC package. Second, the high clock frequency (3.2MHz) and fast transient response further reduce the PCB footprint by minimizing the sizes of the output inductors and capacitors. Third, out-of-phase clocks between the two converters smooth out the input current, reducing the size of the input capacitors. Figure 8 illustrates the PCB footprint with the dual buck IC.

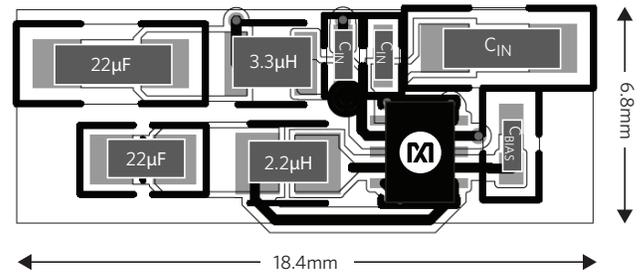


Figure 8. Footprint for the Integrated Dual-Buck Solution:
18.4mm x 6.8mm = 125.1mm²

The integrated dual-buck solution occupies a PCB area of only 125.1mm² resulting in a whopping 22% PCB area reduction.

A second IC can be used for the other two rails depicted in Figure 4 (Buck 2 and Buck 3). The entire remote camera POC is efficiently provided with only two ICs and their related passives.

Low Noise Solution

An additional advantage of the IC is the internally fixed frequency at 3.2MHz, which allows for small external components, reduced output ripple, and operation above the AM band to reduce radio frequency interference. The device operates at constant frequency in forced pulse-width modulation (FPWM) mode and offers optional spread-spectrum frequency modulation to minimize EMI-radiated emissions due to the modulation frequency.

Remote Camera Module

Figure 9 shows Maxim’s remote camera module PCB prototype with two ICs implementing the POC solution for the four power rails.

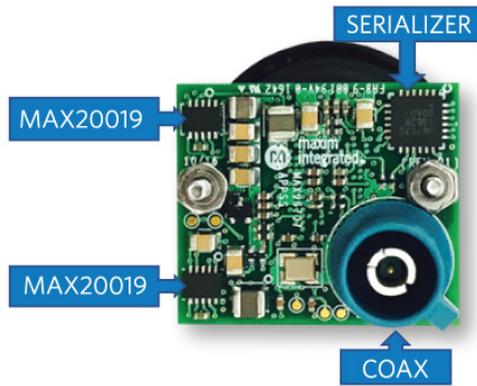


Figure 9. Remote Camera Reference Design

The compact 870mil x 750mil PCB demonstrates the IC’s ability to support a state-of-the-art, miniature, and power-efficient remote camera solution.

Conclusion

Remote camera modules, which include on-board power management systems, must be small, efficient, and cost-effective. Typical power management solutions are space and power inefficient since they utilize multiple ICs and operate with suboptimal efficiency. The MAX20019 dual-buck converter, optimized for cascaded operation, enables remote camera power management solutions that occupy a fraction of the typical PCB space while preserving high levels of efficiency.

Case Study II: How to Shrink Your ADAS ECUs - Wrap the Power Management Around the Signal Chain

The smart car (Figure 10) is loaded with ADAS electronic control units (ECUs), each taking power from the car battery. Each ECU supports a specific car function and has its own dedicated power management. With such a high level of variability, using a discrete approach to the ECU’s power management implementation might seem like the only option; that is, one ad-hoc IC for each building block, such as in the typical system shown in Figure 11. However, this approach is incompatible with another important requirement of these ubiquitous devices, specifically small size. This case study reviews three very different ECU applications and shows that even when multiple building blocks are required, a tailored integrated approach to power management can easily solve this dilemma.

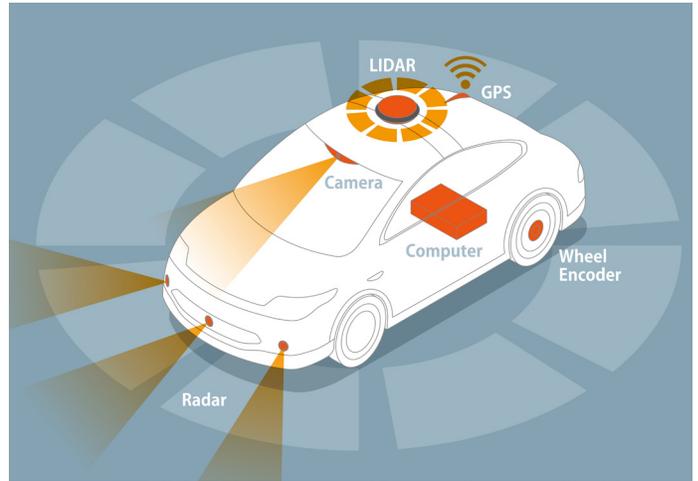


Figure 10. Smart Car Loaded with ADAS Sensors

The Smart Car

Sensing devices in smart, autonomous, or semi-autonomous cars combine millimeter wave radars, micrometer wave lidars, and nanometer wave cameras. When tracking another vehicle in front of the car, the camera is used to find and locate the preceding vehicle, while the radar measures the distance. This information is then used to decide whether it is necessary to slow down or brake the vehicle. In more sophisticated systems, the distance is measured with a radar and a lidar. Unlike both lidar and radar, cameras can see color, making them the best for scene interpretation.

Today’s ADAS Radar Power Solution

Every ADAS-compliant subsystem in the car— whether it be radar, lidar, or camera module—employs a number of voltage regulators, monitors, and watchdog ICs for proper operation. The discrete ADAS radar system in Figure 11 shows six different ICs that implement a power management system for the monolithic microwave IC (MMIC) at the heart of the radar module.

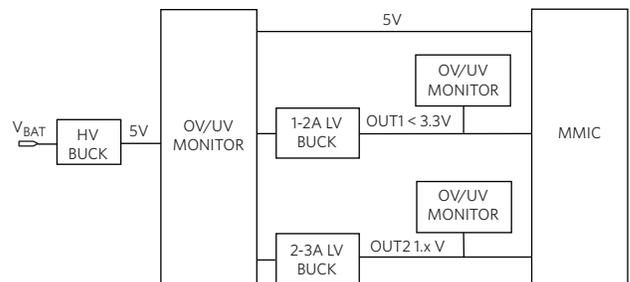


Figure 11. Discrete ADAS Radar Power Management ECU

Often the entire module must be housed on a PCB no bigger than 50mm x 50mm, making it very challenging to accommodate all the necessary components. A non-integrated solution like the one in *Figure 11* is space-consuming and expensive.

Another problem is that proper operation requires the battery to never discharge below 6V (5V output plus 1V headroom for the HV buck converter). Hence, for a cold-crank specification requiring operation down to 4V, this scheme needs an additional pre-boost converter IC. It is estimated that the discrete implementation may require power management with a total solution area of 1250mm², or half of the available space.

On the other hand, a single power management IC would subject all the blocks to the battery voltage variability. Furthermore, an excessive level of integration may create a monster PMIC that is too big to place in the available niches of the square PCB, where the lion’s share of the space is taken up by the signal chain. It is indeed crucial to make the right decision on integration partitioning.

Ideal ADAS Radar Power Solution

An ideal solution should operate with an input voltage at the lowest battery voltage while withstanding load “dump.” *Figure 12* shows six ICs from *Figure 11* that are reduced down to two. The high-voltage (HV) buck converter withstands the load dump and takes the battery voltage down to 3.3V, allowing for cold-crank operation near its output (well below 6V). A high-density, low-voltage PMIC integrates the back-end voltage regulators. With this partitioning, the required area can be conveniently split into two chunks, one for the front-end buck converter (HV BUCK) and one for the PMIC, making it easy to “wrap” the power management solution around the signal-chain circuitry.

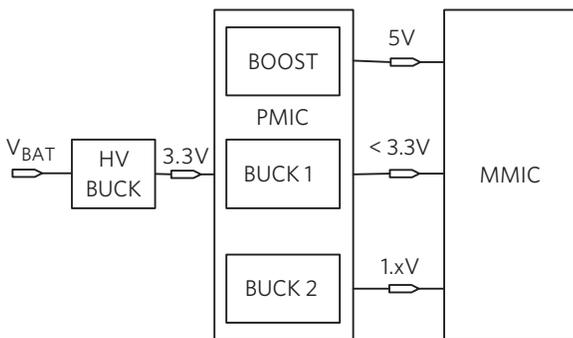


Figure 12. ADAS Radar PMIC

If the ASIL compliance is handled by the microcontroller, a small PMIC that fits this type of ADAS radar application is the **MAX20014**. It provides three high-efficiency, low-voltage DC-DC converter outputs. VOUT1 boosts the input supply up to 8.5V at up to 500mA, while two synchronous step-down converters operate from a 3.0V to 5.5V input voltage range and provide a 0.8V to 3.8V output voltage range up to 3A.

A front-end buck converter (HV BUCK), such as the **MAX20075** (600mA/1.2A), interfaces with the battery.

In this implementation, the total ADAS radar power management solution area is estimated to be 750mm² or about one-third of the available area (vs. half for the non-integrated solution). Additional pin-compatible versions of the IC can support different system requirements.

Ideal ADAS Camera Power Solution

The previous partitioning solution can be replicated for an automotive camera ECU. *Figure 13* shows the PMIC inside the ECU, comprised only of an 8.5V boost converter and a 1.8V buck converter. The 1.8V rail powers the microprocessor. The 8.5V rail is routed through coaxial cables to power the remote cameras.

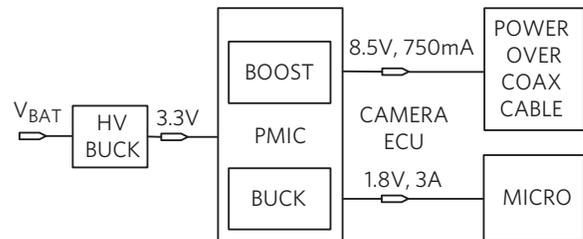


Figure 13. Power PMIC Inside the Camera ECU

A PMIC tailored for ADAS camera ECU applications is the **MAX20414**, which integrates one sync boost and one step-down converter. The total solution area (PMIC + HV BUCK) is estimated to be about 550mm².

Ideal Instrument Cluster Power Solution

The instrument cluster MCU processes the information displayed by the dashboard instrumentation. In **Figure 14**, the system-on-chip (SoC) microcontroller needs two power sources, 1.1V to power its core and 1.8V for the periphery. Here, a dual-buck PMIC like the **MAX20416**, which has a dual-output, low-voltage step-down converter, fits the ADAS microprocessor core and periphery power-supply application. The total solution area (PMIC and HV BUCK) is estimated to be about 560mm².

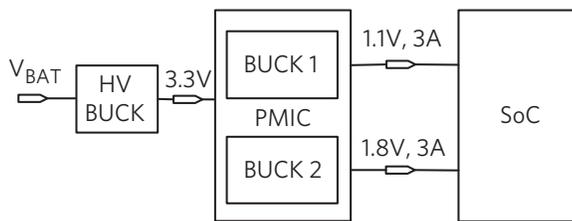


Figure 14. Instrument Cluster PMIC

In each case, the level of PMIC integration needed to fit the solution into a small available space is achieved with a tailored approach along with a load-dump tolerant, high-voltage front-end buck converter. This leads to greater efficiency in terms of cost as well as PCB area.

Additional requirements that these ICs must meet for ADAS applications include: compliance to automotive standards, the ability to operate at high frequency to avoid AM radio-band noise interference, output voltages with $\pm 1.5\%$ accuracy to meet SoC power-supply requirements, spread spectrum for low EMI emissions, and finally, integrated overvoltage and undervoltage monitoring features.

Conclusion

We reviewed three very different automotive ADAS ECU applications. In each case, a tailored approach to integration was proposed. Each system was partitioned into a high-voltage front-end IC and a low-voltage back-end PMIC. The entire power management system was reduced to two ICs, with a level of complexity that is small enough to fit into the limited board space required by ADAS applications by “wrapping” it around the signal chain circuitry.

Case Study III: Choose the Right Front-End Buck Converter for your Automotive ECU

The introduction of 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 ECUs. Each ECU draws power from the car battery through a buck converter. The SoC in ECUs require increasingly higher levels of power—in some cases close to 200W.

Gas-powered vehicles rely on a lead-acid battery to supply the power to the electronic loads (**Figure 15**). 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 case study, 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 15. The Lead-Acid Battery Powers the Gas Car Electronics

Typical ECU System

Figure 16 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.

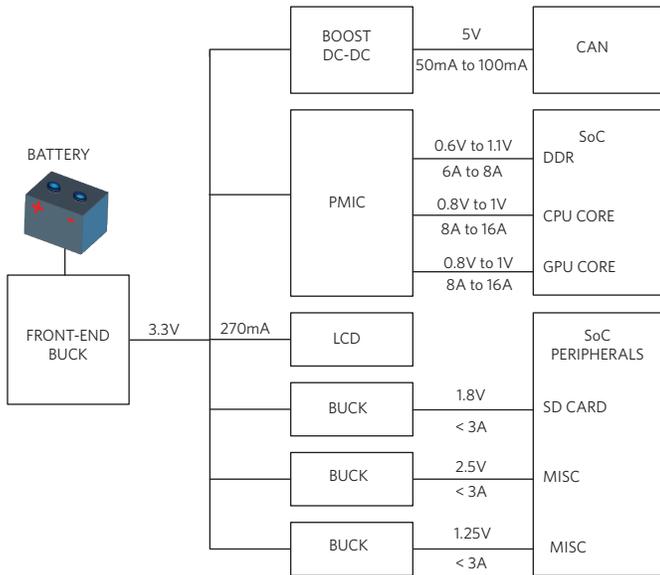


Figure 16. ECU Power Management System

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 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 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 17. For current levels below 8A, a monolithic solution can deliver the best efficiency in the smallest possible PCB area. Monolithic converters integrate MOSFETs, which allows clean and effective sensing of the inductor current across the high-side MOSFET $R_{DS(ON)}$ and avoids 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 optimum layout improves the EMI performance and increases efficiency.

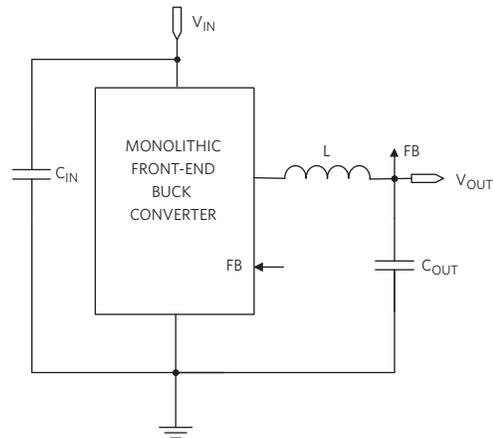


Figure 17. Monolithic Front-End Buck converter

With this implementation, the total PCB area of a 3.3V, 6A solution is 300mm² as shown in Figure 18.

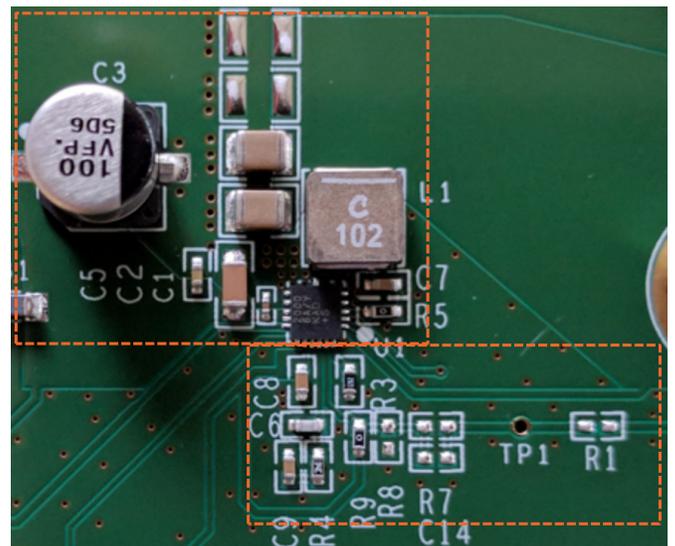


Figure 18. Monolithic Front-End Buck Converter PCB Area (300mm²)

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 plus external low- $R_{DS(ON)}$ MOSFETs (Figure 19). High efficiency can be obtained by proper selection of the MOSFETs, inductor, and optimum PCB layout. Further reduction in losses can be achieved by direct current resistance (DCR) current sensing, thus avoiding 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 ($\frac{L}{R_L}$) is matched to the external network's time constant ($R_S \times C_S$), then the voltage across the capacitor C_S equals the voltage across the inductor parasitic resistance R_L , of known value, thus allowing the derivation of the inductor current.

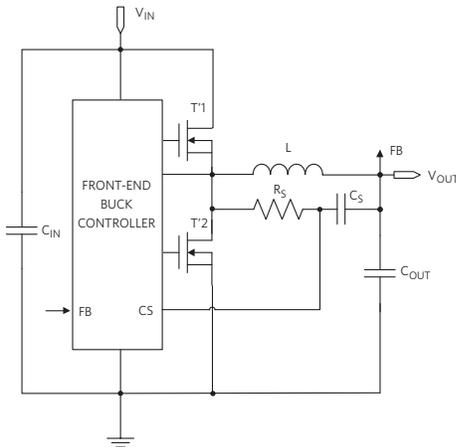


Figure 19. Front-End Buck Controller with External MOSFETs

With this implementation, the PCB area of a 3.3V, 7A solution, is 500mm² as shown in Figure 20. 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.

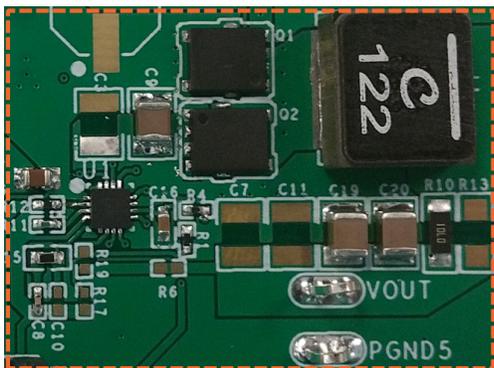


Figure 20. Controller-Based Front-End Buck PCB Area (500mm²)

High Level of Complexity

For systems requiring 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 21.

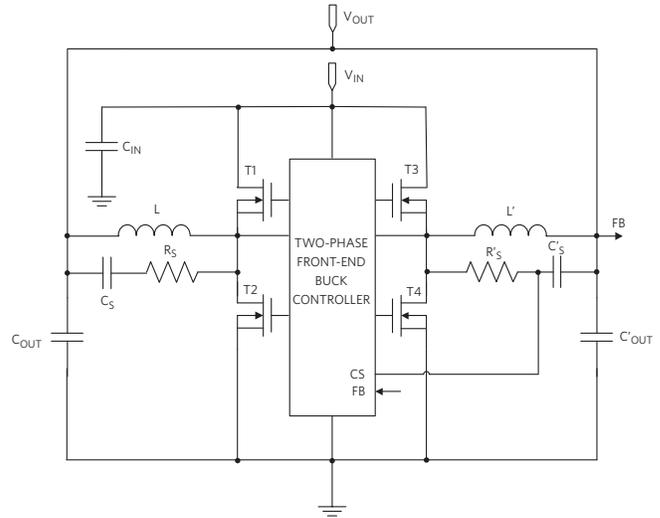


Figure 21. Two-Phase Interleaved Front-End Buck Converter

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 22 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.

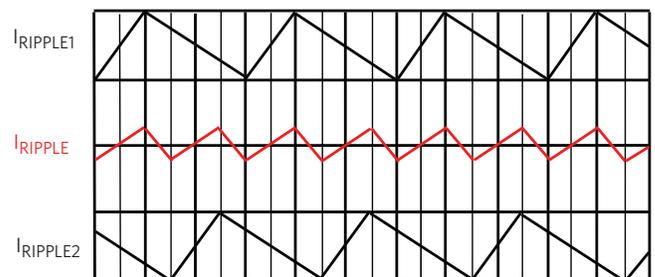


Figure 22. Two-Phase Current Ripple Reduction vs. Time

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} , I_{IN2} in Figure 23). 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.

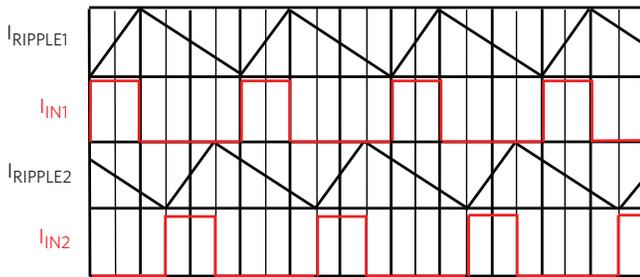


Figure 23. Two-Phase Output Ripple Currents and Input Currents vs. Time

Additionally, as shown in *Figure 24*, two-phase (2 Φ , shown in red) is more efficient than single-phase (1 Φ , shown in blue) when the two schemes are running 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.

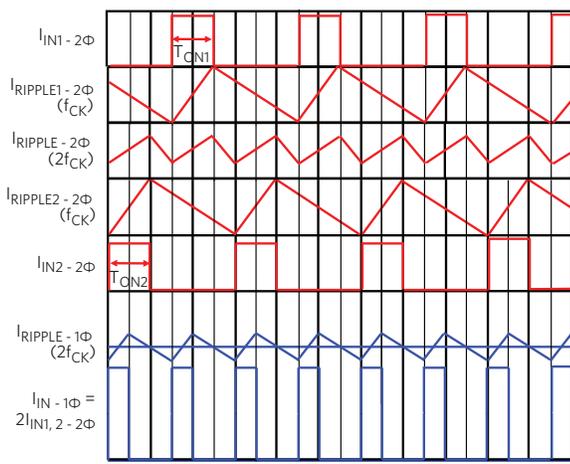


Figure 24. Two-Phase vs. Single Phase Currents vs. Time

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 pushed higher 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 multi-phase operation reduces the current in each phase ensuring optimal sizing for passives.

Solution Example: Medium Complexity System

The **MAX20098** is a 2.2MHz synchronous step-down controller IC with 3.5 μ A 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 synchronous 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

Gas-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 case study, 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 levels of power, a two-phase interleaved approach yields the best results in terms of efficiency and size.

Challenge 2 - Safety and Reliability

In this section, we will first discuss the safety of the electric path from the battery to remote cameras. Electric safety is enhanced using appropriate protectors and the adherence to ASIL-B and ASIL-D safety specifications. Subsequently, we will review motorist safety. Visible LED drivers play a critical role in preserving and enhancing the sophisticated lighting patterns that improve motorist visibility. Similarly, IR LED drivers play an important role in driver monitoring system (DMS) applications, checking the motorist's state of alert. We will highlight the importance of power-efficient solutions that reduce heat generation and keep the electronics cool, thereby improving reliability.

Case Study I: Providing a Safe Power Path from the Car Battery to Remote Cameras

Modern cars are loaded with sensors aimed at making the driving experience safe and accident-free (Figure 25). Cameras are a big part of the ADAS toolset, providing views of blindspots previously unavailable to the driver, traffic sign recognition, pedestrian detection, and aiding with vehicle parking. All these sensors strategically located along the vehicle periphery need electric power to operate.

Along the power path from the car battery to the remote

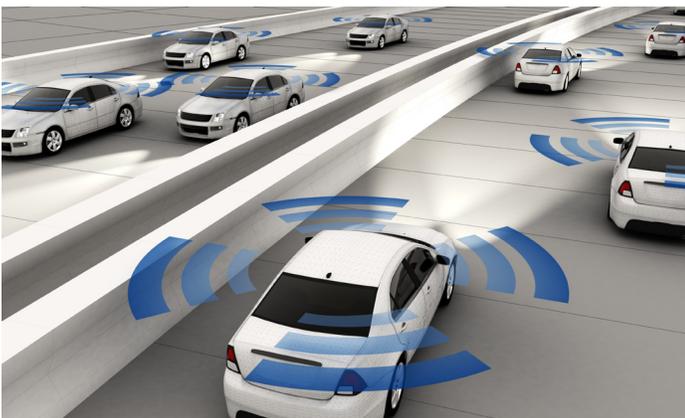


Figure 25. Intelligent Highway Environment

cameras, there are many challenges. The front-end regulator interfacing with the car battery must support cold crank and start/stop while withstanding “load dump” and meeting ASIL-B and ASIL-D safety specifications. The current and voltage going into the camera modules via the coaxial cables must be monitored and controlled for various types of faults. The remote camera modules, with their on-board power management systems, must be small, efficient, and cost-effective.

This case study reviews the full power management path, from car battery to remote cameras, and proposes a system-level solution to meet the power path challenges of size, efficiency, and safety.

Remote Camera System

Figure 26 shows an example of a surround-view camera system. Here a buck-boost converter connects to the battery and provides DC power to the remote cameras through a quad protector IC, a bank of AC-blocking coils (L), and four coaxial cables. A quad deserializer connects the microprocessor to the remote cameras via the bank of AC-coupling capacitors (C) and the same coaxial cables.

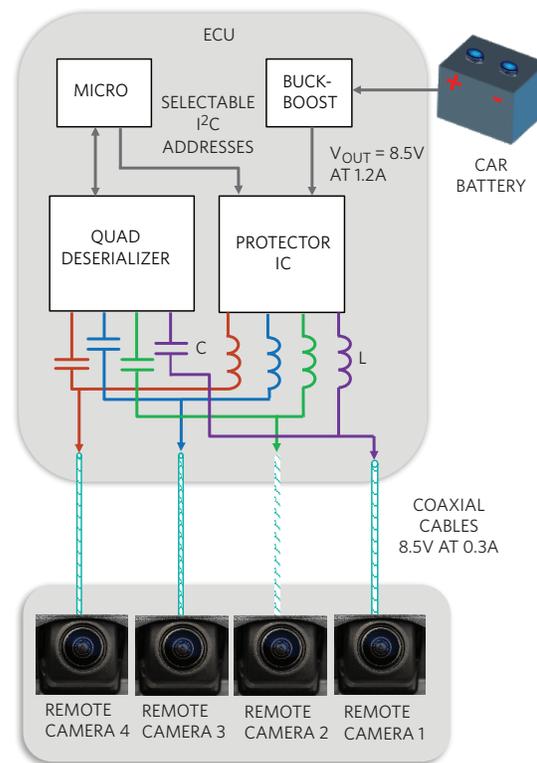


Figure 26. Surround-View Camera System

Single-Channel Power Path

A power management section of a single channel is highlighted in Figure 27. The buck-boost converter interfaces with the battery, while the protector IC protects from various fault conditions that may occur along the coaxial cable. On the remote camera module, two dual-buck converters power the imager and the serializer.

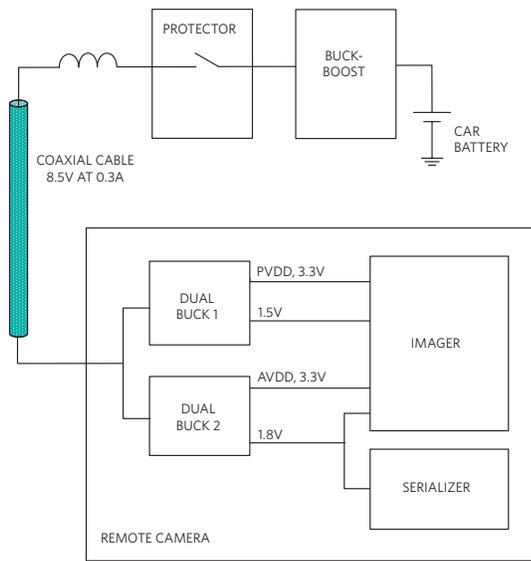


Figure 27. Remote Camera Single-Channel Detail

In the following sections, we will discuss each element in the power chain.

Buck-Boost for Start/Stop and Cold Crank

Internal combustion engine cars can save as much as 10% in fuel consumption by shutting down the motor when the car is idle. The car battery is typically at 13.5V but can be as high as 16V on a fully charged battery. Vehicles that employ start-stop technology experience large voltage dips when the engine starts, so the power source lower limit can be well below the typical 13.5V and can often be 6V or even lower.

Cold crank is an even more severe condition incurred by internal combustion engines. In cold weather, the car battery voltage at the start of the engine can dip as low as 5V or lower. It is worth noting that electric cars do not have to deal with either problem.

A buck-boost converter keeps its output in regulation in the presence of wide input voltage swings above and below its output. Figure 28 shows the buck-boost power train architecture and its operation table. For $V_{IN} > V_{OUT}$, the IC regulates in buck (step-down) mode, while for $V_{IN} < V_{OUT}$, it seamlessly transitions to boost (step-up) operation ensuring that the V_{OUT} output remains in tight regulation and is glitch-free. The entire battery voltage range is covered in a switch-mode, high-efficiency fashion.

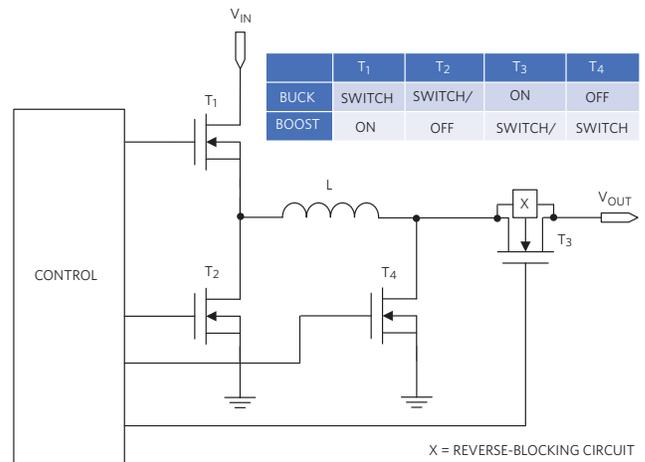


Figure 28. Buck-Boost Converter

STG and STB Protection

In vehicles, some of the most common problems with the cables and wires that extend throughout the car are the damage to the wires themselves and the accidental connection to the vehicle ground or main battery supply.

Connecting to ground is potentially dangerous because devices on the wire can produce significant power that gets dumped into the vehicle ground, potentially causing them to overheat and break if they do not have built-in protection.

Connecting to the battery supply line is also potentially dangerous because an electrical device that is meant to run at only 5V can suddenly be connected to a source with a higher-than-permissible voltage. This can cascade to an even worse situation where the device gets damaged by the car battery, then draws a lot of power because the batteries can produce hundreds of amperes. It is not outside the realm of possibility for things to explode.

In automotive terms, an accidental connection to ground or battery is called "short-to-ground" (STG) or "short-to-battery" (STB), respectively.

The STB protection prevents an overvoltage on the outputs. The STG protection limits the device sink/source current that results from the short circuit.

It is important to protect against STG and STB directly on the front-end of the battery power source. Safety features on the front-end help to protect all downstream circuitry from damage.

Integrated Buck-Boost Converter

A suitable buck-boost converter will integrate both control and four DMOS power transistors with low $R_{DS(ON)}$ and high efficiency within a small package. The IC must meet the most stringent automotive quality and reliability requirements. Output disruptions due to input voltage variations can be minimized by the regulator’s fast line-transient response. As an example, in **Figure 29**, a positive input transient from 3.5V to 13.5V causes a deviation of only +50mV on a 5V output, with only 22 μ F on the output! Conversely, in **Figure 30**, a negative input transient also produces only a -50mV deviation on the output. A fast load-transient response will help minimize the size of the output passives. The IC should also be 40V load-dump tolerant.

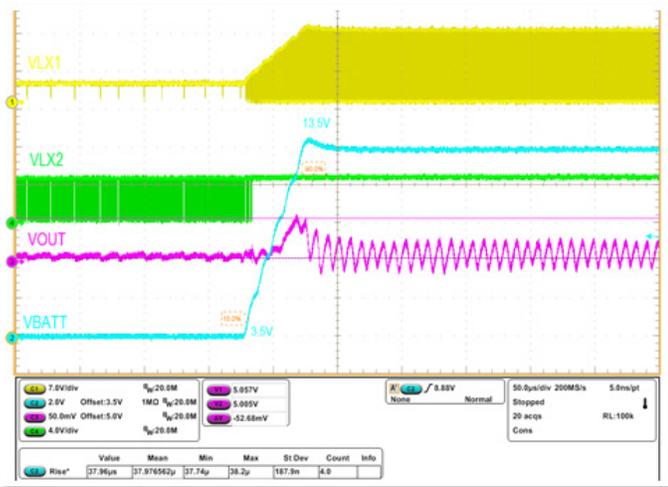


Figure 29. Positive Line-Transient Response

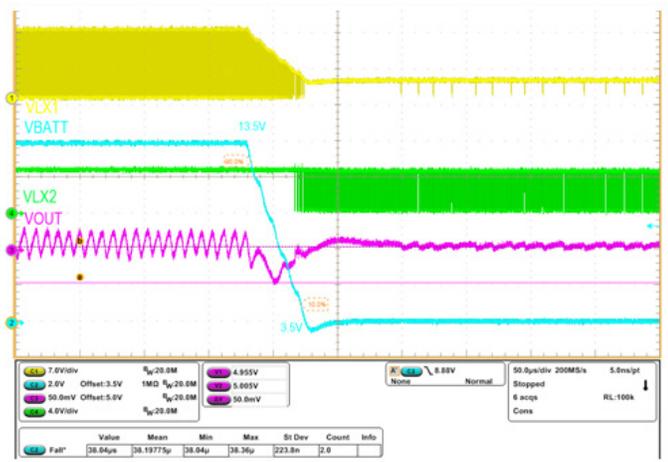


Figure 30. Negative Line-Transient Response

Output Protection

The quad power camera protector IC in **Figure 31** limits the load current to each of the four output channels. Each output is individually protected from STB, STG, and overcurrent conditions. The low $R_{DS(ON)}$ of the two back-to-back DMOS transistors assure low power dissipation, while a small package reduces PCB size. The IC should be equipped with an enable input and an I²C interface to read the diagnostic status of the device. An on-board ADC enables the reading of the current through each switch. The ASIL-B and ASIL-D-compliant **MAX20087** includes support for reading additional diagnostic measurements through the ADC, ensuring higher-fault coverage than the non-ASIL version (**MAX20086**).

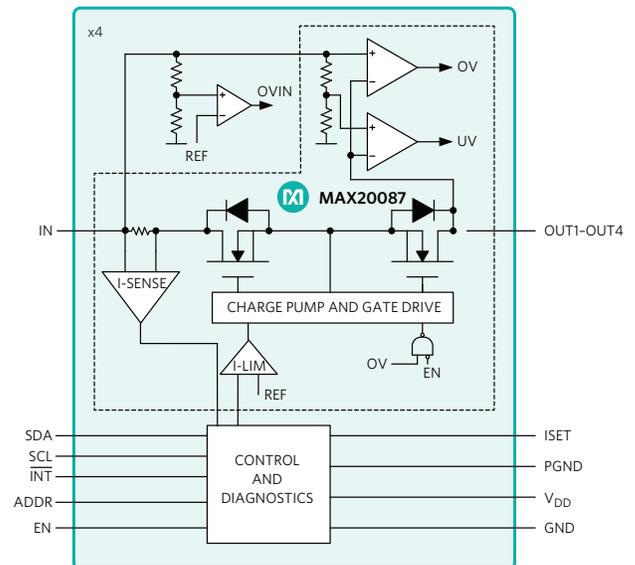


Figure 31. Input Current and Voltage Protection

Remote Camera Power

The remote camera modules, with their on-board power management systems, must be small, efficient, and cost-effective. The integration of two buck converters for cascaded operation, both working at or near full load, and a high duty cycle is ideal for this application (**Figure 32**). By covering the four remote camera rails with two cascaded dual-buck converter ICs, we save space and preserve efficiency. More details about this solution were discussed in the Challenge 1: Case Study I section.

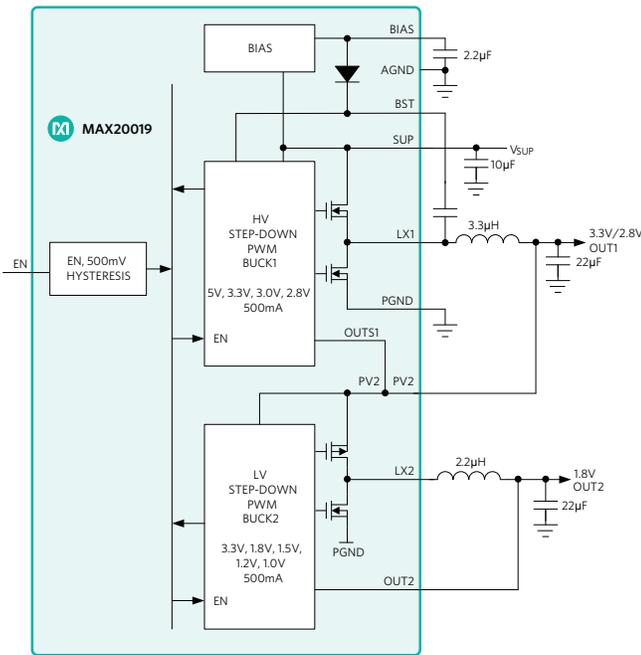


Figure 32. Dual Buck Converter Cascade

Conclusion

Along the power path from the car battery to the remote camera there are several technical challenges. At the interface with the battery, there are severe line transients induced by load dump, start/stop, and cold-crank operation. Transmission of power and data on long coaxial cable bundles requires protection from various short-circuit modes (STG, STB). Remote cameras are small and require space- and power-efficient solutions. For each challenge, we proposed solutions that meet the stringent requirements for automotive quality and reliability, are power-efficient, and occupy a small PCB space. The MAX20087 quad power camera protector is a compact, efficient protection IC. The dual MAX20019 cascade buck converter configuration delivers high efficiency in a small space. This triplet of ADAS ICs effectively provides power and protection along the path of the car battery to the remote cameras.

Case Study II: How to Protect Your Automotive Power Supply

It's easy to think that designing an automotive power supply would be trivial. A car battery is nominally +12V and the power supply only needs to account for this input voltage...right?

Unfortunately, this is not the case for automotive systems connected directly to the battery. Car batteries fluctuate between +9V to +16V during normal operation and system voltages can deviate even further during cold-crank or load-dump conditions.

Cold crank occurs when the battery supplies a large current to start the engine, causing the battery voltage to droop to +3V ±0.2V (worst case +2.8V). The 3V power supply is typically maintained for 15ms before recovering to a value of 6V, which could remain for a couple seconds. **Figure 33** and **Table 1** display a typical cold-crank timing diagram from ISO (International Organization for Standardization) 7637-2. Cold crank causes current from the load's bulk capacitance to discharge into the battery, depleting system hold-up time and allowing unregulated current into the battery.

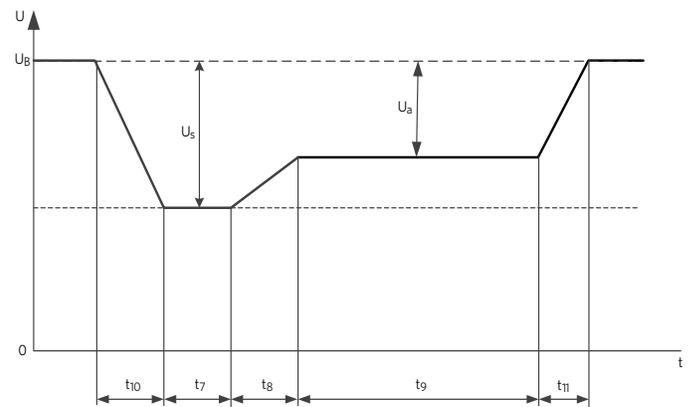


Figure 33. Automotive Cold-Crank Timing Diagram

Table 1. Voltage and Timing Specification for Automotive Cold Crank

Parameter	12V System	24V System
U_s	-6V to -7V	-12V to -16V
U_a	-2.5V to -6V with $ U_a \leq U_s $	-5V to -12V with $ U_a \leq U_s $
R_i	0Ω to 0.02Ω	
t_7	15ms to 40ms ^a	50ms to 100ms ^a
t_8	≤ 50ms	
t_9	0.5s to 20s ^a	
t_{10}	5ms	10ms
t_{11}	5ms to 100ms ^b	10ms to 100ms ^b

^a The value used should be agreed between the vehicle manufacturer and the equipment supplier to suit the proposed application.
^b $t_{11} = 5ms$ is typical of the case when engine starts at the end of the cranking period, while $t_{11} = 100ms$ is typical of the case when the engine does not start.
^c $t_{11} = 10ms$ is typical of the case when engine starts at the end of the cranking period, while $t_{11} = 100ms$ is typical of the case when the engine does not start.

A second condition that causes transient voltages on automotive power supplies is load dump. Load dump occurs when the battery is disconnected from the load while the alternator is charging the battery. This can cause the system bus to have voltages exceeding +100V! **Figure 34** and **Table 2** denote parameters relating to load-dump situations from ISO 7637-2. Load dumps can cause system ICs to experience damaging voltages and currents.

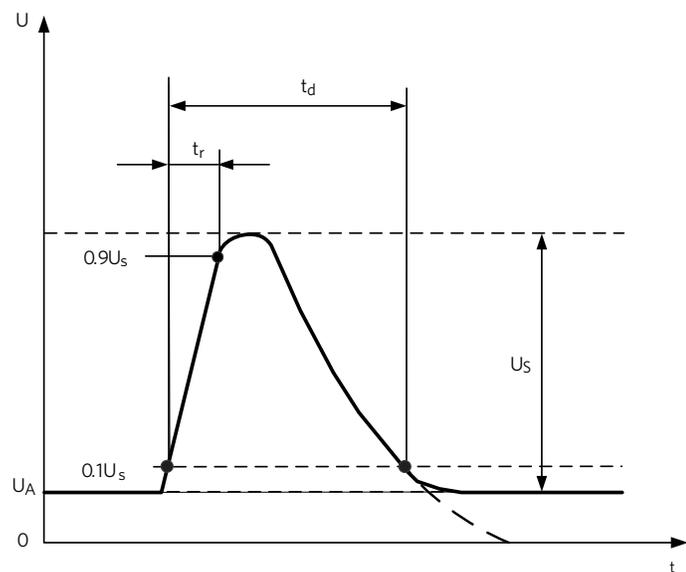


Figure 34. Automotive Load Dump Timing Diagram

Table 2. Automotive Load-Dump Specifications

Parameter	12V System	24V System
U_s	65V to 87V	123V to 174V
R_i	0.5Ω to 4Ω	1Ω to 8Ω
t_d	40ms to 400ms	100ms to 350ms
t_r	$(10 \frac{0}{-5})ms$	

These are two situations that create damaging transients discussed in ISO 7637-2. With the increase of electrical content within cars, more systems are required to remain operational during these events, especially ADAS systems that are designed to make intelligent operational decisions for the car.

Traditional Protection Approaches

A passive diode between the car battery and the system can protect against reverse currents flowing during cold crank but faces the drawbacks of a typical 0.7V forward voltage drop—high power dissipation, increased thermal dissipation, and a decrease in system efficiency.

Transient-voltage-suppressor (TVS) diodes can clamp voltages to protect against overvoltage surges but this still exposes devices to high voltage levels. TVS diodes work better at higher voltages because they don't need to dissipate as much energy. A 60V TVS is a popular value, meaning all components connected to this bus must withstand 60V transients. Many recently released switching regulators can survive this voltage but can have operating issues, such as efficiency decrease or failure to properly regulate the output and stops that supply downstream rails.

Maxim's Full Protection: MAX16141

To protect against reverse-current and overvoltage conditions, the **MAX16141** ideal diode controller was developed to offer a full suite of protection for automotive systems, including protection against reverse current, overcurrent, reverse voltage, undervoltage, overvoltage, and thermal shutdown. The MAX16141 protects the system from all these events between the range of -36V to +60V.

Figure 35 shows the typical application circuit for the MAX16141.

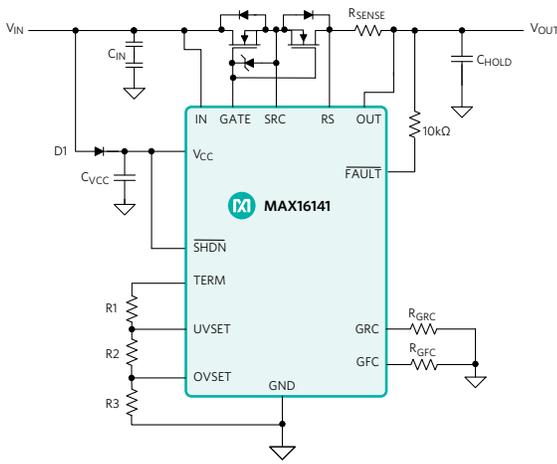


Figure 35. MAX16141 Ideal Diode Controller Typical Application Circuit

The MAX16141 has an advantage over traditional discrete diodes by protecting against reverse-current events due to the low $R_{DS(ON)}$ of the N-FETs. This makes the system more efficient in high load-current applications. Two back-to-back N-FETs create a true disconnect between the battery and the system circuitry during fault events and user-selected shutdown mode. An internal comparator monitors reverse-voltage events between the IN and OUT pins to factory-trimmed threshold voltages of 10mV, 20mV, 30mV, and 40mV. Once the desired threshold is reached, the gates of the N-FETs discharge within 1 μ s (max) to completely disconnect the battery from the application circuitry. The rapid response time of the MAX16141 helps minimize C_{HOLD} discharge into the battery. This effectively increases the hold-up time for the application circuitry and helps reduce the required bulk capacitance, labeled C_{HOLD} in Figure 35.

The UVSET and OVSET pins provide flexible architecture to set the undervoltage and overvoltage levels at which the MAX16141 disconnects the battery from the application circuitry. This allows downstream circuitry to operate using the energy from the bulk capacitance at their typical operating value during these fault events. This also prevents circuitry from experiencing a high-voltage surge when only using a TVS diode.

The fault output flag transitions low during any of the fault events so that critical circuitry can save important data prior to depleting the bulk capacitance charge, which ensures a safer and more reliable system.

A couple of the features contained in the MAX16141 have been discussed that specifically pertain to cold-crank and

load-dump situations. There are additional features of the MAX16141 including inrush current control through gate ramp/fall options, overcurrent protection, thermal shutdown, sleep mode, shutdown mode, and fast recovery for short brownout conditions.

Additional ICs to Protect Automotive Systems

The MAX16141 can be used for applications that require full-encompassing protection. Another ideal diode controller family is the MAX16126/MAX16127. These were designed to protect against undervoltage and overvoltage conditions as well as thermal shutdown. The MAX16126/MAX16127 have a greater protection range than the MAX16141, extending from -36V to +90V.

Like the MAX16141, the MAX16126 completely disconnects the battery from the application circuitry, whereas the MAX16127 acts as a regulator to clamp the voltage at a specific value during overvoltage events. Figure 36 shows the typical application circuit of the MAX16127.

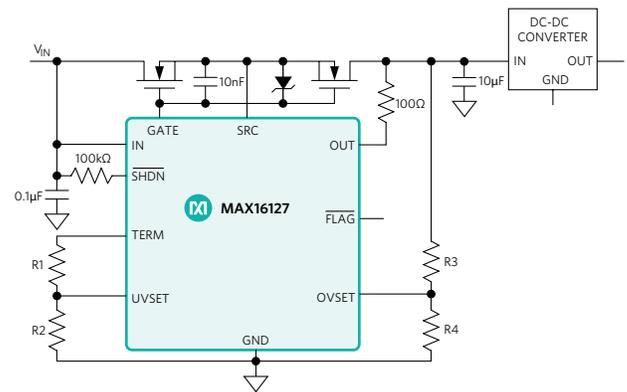


Figure 36. MAX16127 Typically Application Circuit

The MAX16126/MAX16127 are designed for systems that need full protection from undervoltage and overvoltage conditions or need protection as high as +90V.

Conclusion

Traditional protection schemes that implement discrete diodes do not meet the requirements of today's automobiles. Electronic content in cars is rapidly expanding, increasing the electrical demands for not only the automotive battery but overall operational integrity. To maximize safety and reliability, devices like the MAX16141 and MAX16126/MAX16127 ideal diode controller families are needed to ensure maxim uptime and protection of application circuitry.

Case Study III: Achieve Superior Automotive Exterior Lighting with a High-Power Buck LED Controller

High-power LEDs are becoming very popular in automotive exterior lighting design (*Figure 37*) thanks to superior lighting characteristics and efficiency. The electronics supporting LEDs must in turn be fast, efficient, and accurate for controlling light intensity, direction, and focus. They must support a wide input voltage range and operate outside the car radio's AM frequency band to avoid EMI. They must also support complex light patterns required in LED matrixes for adaptive front-lighting systems. This case study reviews a typical LED power management solution and presents a novel buck controller IC that enables a fast, efficient, and accurate LED lighting solution.

LEDs in Automotive Exterior Lighting

LEDs are taking the automotive industry by storm due to significant advantages over traditional technologies. The superior clarity of the white light in LED headlights improves driver reaction time. Adaptive front-lighting systems (AFS), enabled by LED matrixes, produce fast, complex light pattern changes that improve visibility for drivers in poor light conditions. At night, in response to the beams of an incoming car, AFS can automatically adjust the light pattern, preventing the oncoming driver from being blinded by harsh lighting. The LED illumination rise-time is twice as fast as that for incandescent sources, so that LED-based brake lights illuminate quicker and provide advanced warning to drivers, increasing road safety. Finally, LEDs consume less power than their incandescent counterparts, leading to substantial advantages in fuel consumption. LED controllers, the electronics that operate LEDs, play an important part in preserving and enhancing the inherent LED qualities of clarity, speed, and efficiency.



Figure 37. LED-Powered Car Headlight

Powering the LEDs

LEDs have many automotive applications and are used in diverse configurations from a single LED to LED strings and matrixes. High-brightness LEDs (HB LEDs) require constant current for optimal performance. The current correlates with junction temperature and therefore color. Accordingly, HB LEDs must be driven with current, not voltage. The power source can range from a 12V car battery up to a 60V boost converter to accommodate a long string. Vehicles that employ start/stop technology experience large battery voltage dips when the engine starts, causing the battery voltage to droop well below the typical 12V, sometimes even 6V or lower.

Dimming

Dimming is a ubiquitous function in many automotive applications and an important safety feature for LED headlights. The human eye can barely detect light dimming from 100% to 50%. Dimming must go down to 1% or less to be clearly discernable. With this in mind, it is not surprising that dimming is specified by a ratio of 1000:1 or higher. Given that the human eye, under proper conditions, can sense a single photon, there is practically no limit to this function.

Since current must be kept constant to preserve color, the best dimming strategy for LEDs is PWM (pulse-width modulation), where the light intensity is modulated by time-slicing the current rather than by changing the amplitude. The PWM frequency must be kept above 200Hz to prevent the LED from flickering.

With PWM dimming, the limit to the minimum LED "on/off" time is the time it takes to ramp up/down the current in the switching regulator inductor. This may add up to tens of microseconds of response time, which is too slow for LED headlight cluster applications that require fast, complex dimming patterns. Dimming in this case can only be performed by individually switching on/off each LED in a string by means of dedicated MOSFET switches (SW_{1-K} in *Figure 38*). The challenge then for the current control loop is to be fast enough to quickly recover from the output voltage transient due to switching in and out of the diodes.

LED Controller Characteristics

To be most effective, the LED controller must accommodate a wide input voltage range and have a fast-transient response as discussed earlier. A high, well-controlled switching frequency, outside the AM frequency band, is required to reduce radio frequency interference and meet EMI standards. Finally, high efficiency reduces heat generation, improving the LED light system's reliability.

The Headlight System

Sophisticated headlight systems utilize a boost converter as a front-end to manage both the variabilities of the input voltage (dump or cold-crank) and the EMI emissions. The boost converter delivers a well-regulated and sufficiently high output voltage (Figure 38). Dedicated buck converters, working from this stable input supply, can then handle the complexities of controlling the lamp’s intensity and position by allowing each buck converter to control a single function, such as high beam, low beam, fog, daytime running lights (DRL), position, etc.

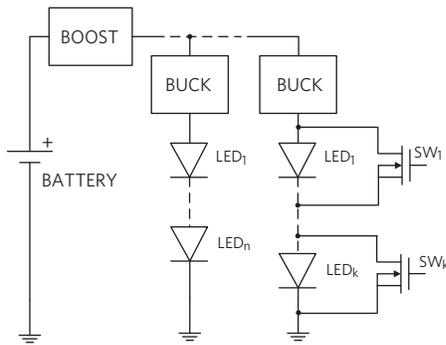


Figure 38. Advanced LED Lighting System

In this application, each buck converter’s main control loop sets the current in its LED string, with two secondary loops that implement the overvoltage and overcurrent protection.

Typical High-Power Buck LED Driver Solution

A typical buck LED driver solution is shown in Figure 39. It uses a p-channel, high-side MOSFET, with relatively high $R_{DS(ON)}$ compared to an n-channel transistor, and a nonsynchronous architecture that relies on the Schottky diode D for current recirculation. Both are sure signs of an inefficient implementation.

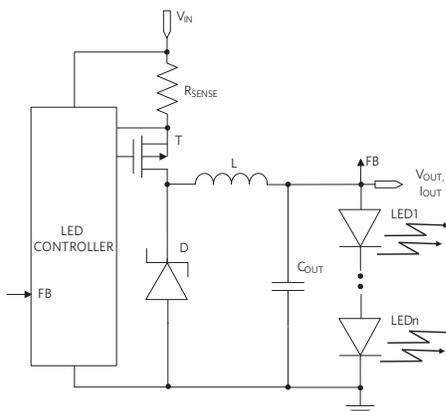


Figure 39. Typical Nonsynchronous Buck LED Driver

Typical Transient Response

Figure 40 shows another shortcoming of a typical solution in its transient response. In this test, in a string of 12 LEDs, the number of powered-up diodes has instantly risen from eight to twelve. The resulting output voltage step produces a current and voltage fluctuation that takes tens of microseconds to extinguish. A high-ratio PWM dimming circuit will sample this current for only a few initial microseconds where the amplitude is dipping, resulting in incorrect dimming brightness and color.

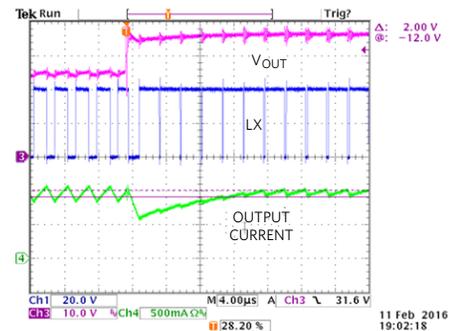


Figure 40. Typical Transient Response with Hysteresetic Buck

Synchronous High-Power Buck LED Driver Solution

An ideal solution should meet the requirements of a wide input voltage range, fast transient response, high and well-controlled switching frequency, all while enabling high efficiency with synchronous rectification. The MAX20078 LED controller enables such a solution (Figure 41).

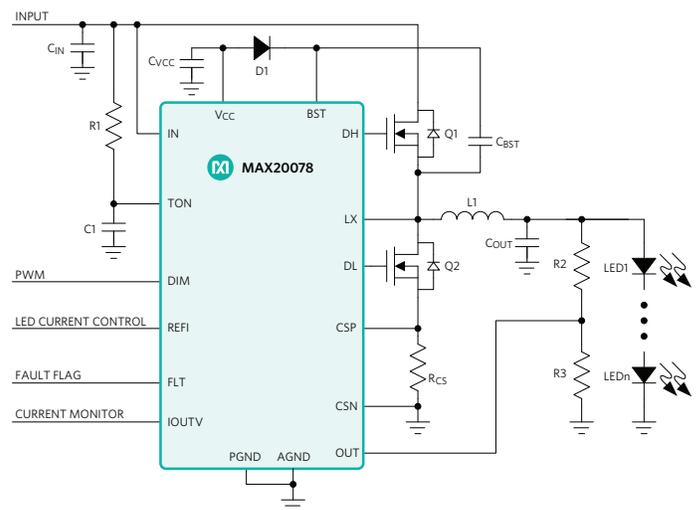


Figure 41. Synchronous High-Power Buck LED Driver

The MAX20078 LED controller uses a proprietary average current-mode-control scheme to regulate the inductor current while maintaining a nearly constant switching frequency. It operates over a wide 4.5V to 65V input range at switching frequencies up to 1MHz and includes both analog and PWM dimming. It is available in a space-saving (3mm x 3mm), 16-pin TQFN (regular or SW) or a 16-pin TSSOP package.

High Efficiency

Figure 42 shows the MAX20078-based LED driver's efficiency vs. supply voltage. Two 107mΩ synchronous rectification MOSFET transistors provide high efficiency over a wide range of supply voltages.

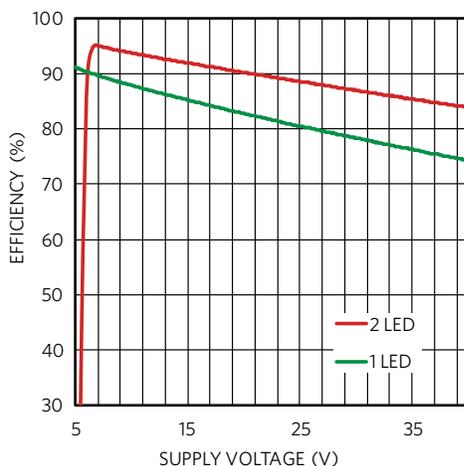


Figure 42. MAX20078 Solution Efficiency vs. Supply Voltage

Accurate Light Intensity Control

The proprietary architecture of the MAX20078 yields a transient response that is virtually error-free compared to that shown in Figure 40. In Figure 43, the increase in the number of diodes from eight to twelve does not produce any appreciable fluctuation in the output voltage or current.

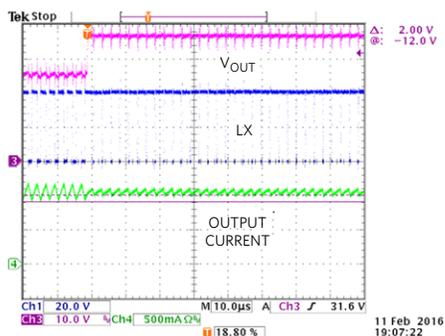


Figure 43. MAX20078 Transient Response

High Frequency of Operation

The on-time of the MAX20078 can be programmed for switching frequencies ranging from 100kHz up to 1MHz. Its on-time varies in proportion to both input voltage and output voltage, resulting in a switching frequency that is virtually constant. A high and well-controlled switching frequency, outside the AM frequency band, is easily set with the MAX20078. Radio frequency interference is reduced while the spread-spectrum feature meets EMI standards.

MAX20053 Buck Converter with Integrated MOSFETs

For compact lighting applications with currents up to 2A, the MAX20053 is an ideal solution. The fully synchronous 2A step-down converter integrates two low $R_{DS(ON)}$ 0.14Ω (typ) MOSFETs, assuring high efficiencies up to 95%. The high level of integration yields minimum PCB area occupation.

With its 4.5V to 65V input supply range, the MAX20053 easily withstands the battery load dump, making it ideal as the front-end buck converter in DMS applications. This feeds the infrared (IR) circuitry that checks on the driver state-of-alert.

The boost converter in Figure 38 can be implemented with the MAX16990/MAX16992 36V, 2.5MHz automotive boost/SEPIC controllers.

Conclusion

We have reviewed the many challenges in powering complex LED lighting systems and the requirements for optimal LED system performance. We showed how the MAX20078 meets those challenges using a novel LED controller architecture that provides not only accurate average current control but high-frequency operation outside the AM radio band, good transient response for high-ratio dimming accuracy, and high efficiency for minimum power consumption. These features in turn enable superior automotive exterior lighting, which is more efficient, supports complex light patterns and more accurately controls light intensity, direction, and focus.

Case Study IV: IR Camera for DMS

Infrared (IR) cameras, utilizing an IR-LED diode in combination with a CMOS sensor, help recognize hazardous microsleep that affects motorists. The advantage of using infrared is its invisibility to the human eye and its ability to operate day and night. Image analysis processes information to determine if the driver is fatigued or distracted. With a typical forward voltage of 2.8V and a forward current of 1A, the electronics that drives the IR LED is directly connected to the battery.

As an example, the MAX20050 buck LED driver is an ideal solution (*Figure 44*). The fully synchronous, 2A step-down converter integrates two low RDS(ON) 0.14 Ω (typ) MOSFETs, assuring high efficiencies up to 95%. With its 4.5V to 65V input supply range, the MAX20050 can easily withstand battery load dump, making it ideal as a front-end buck converter in DMS applications. It helps feed the IR circuitry that checks on the driver's state-of-alert. This high level of integration yields minimum PCB area occupation.

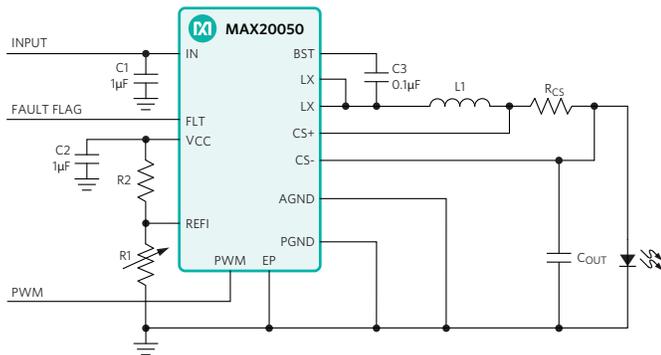


Figure 44. IR LED Driver Solution

The MAX20050/MAX20052 utilize internal loop compensation to minimize component count, while the MAX20051/MAX20053 use external compensation for full flexibility. The MAX20050/MAX20051 have an internal switching frequency of 400kHz, while the MAX20052/MAX20053 have an internal switching frequency of 2.1MHz.

For higher power, the MAX20078 synchronous buck LED controller can be utilized. For higher voltage applications, the MAX20090 high-voltage HB LED controller is an excellent choice.

Case Study V: Improve Your Automotive ECU Design with a Low- I_Q Buck Converter

High-end cars require close to a hundred ECUs, each taking power from the car battery with the intermediation of an on-board buck converter. As an example, an engine control unit is illustrated in *Figure 45*. Many ECUs must remain in standby mode even when the ignition key is off. Their standby currents add up, increasing the rate of car battery discharge. Accordingly, the quiescent current specification for these units is getting tougher to meet. The ECU buck converter must meet many other challenges inherent to the automotive environment. This case study reviews the challenges of designing an ECU buck converter, from low quiescent current and low noise to high reliability. It introduces a new family of buck converters that addresses these challenges.

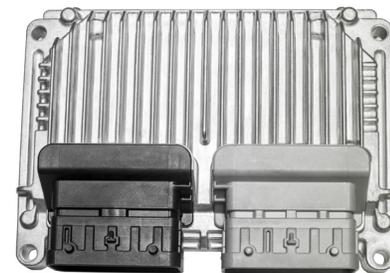


Figure 45. Engine Control Unit

ECUs in the Car

ECUs are small computing modules that control most of the systems in a modern car. ECUs are connected via a controller area network (CAN) and control the car's engine, power windows, brakes, airbags, lights, entertainment system, steering functions, and more (*Figure 46*). To minimize the battery discharge, car manufacturers are specifying quiescent currents for ECUs as low as 100 μ A.

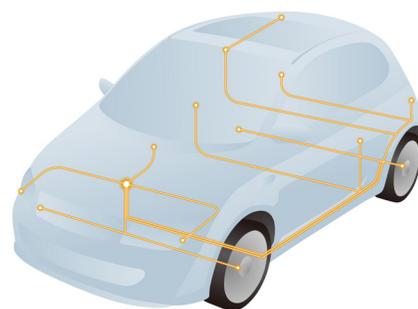


Figure 46. CAN-Connected ECUs in a Car

Powering the ECU

The block diagram of a typical ECU is shown in *Figure 47*. The on-board buck converter powers the MCU, CAN, and I/Os while interfacing the battery via a pre-boost converter. A high and well-controlled PWM switching frequency, above the AM band, is required to reduce radio frequency interference while spread spectrum is necessary to meet 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 CAN. Finally, a high-efficiency buck converter will reduce ECU heat generation, improving its reliability.

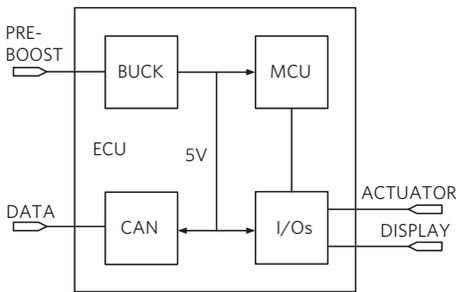


Figure 47. ECU Block Diagram

Low Quiescent Current Solution

The MAX20075 (600mA) and MAX20076 (1.2A) are excellent examples of low quiescent current, 36V synchronous buck converters. The devices, which normally switch at 2.1MHz, automatically enter skip mode at light loads with a typical 3.5µA ultra-low quiescent current at no load (*Figure 48*, 14VIN, 3.3VOUT).

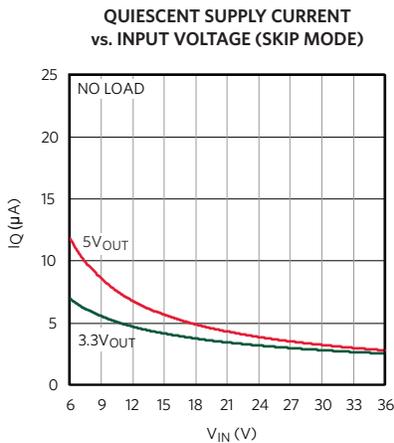


Figure 48. IQ vs. VIN Curves

Low Noise Solution

An internally fixed frequency of 2.1MHz allows for small external components, reduced output ripple, and operation above the AM band to reduce radio frequency interference. The devices operate at constant frequency in forced PWM mode (FPWM) and offer pin-enabled spread-spectrum frequency modulation designed to minimize EMI-radiated emissions due to the modulation frequency. *Figure 49* shows a spread-spectrum-enabled device that easily passes the EMI requirements for radiated emissions in the FM band.

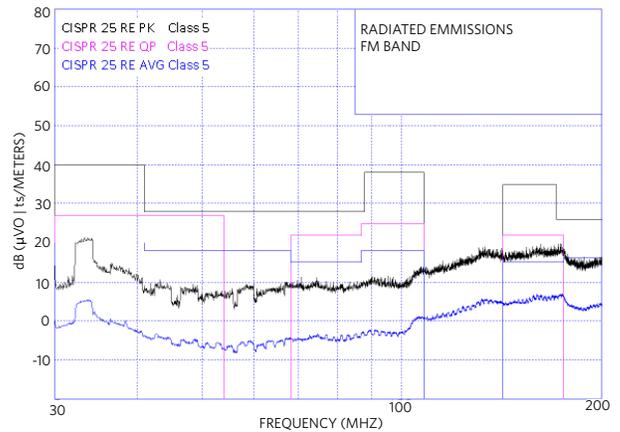


Figure 49. IQ vs. VIN Curves

High-Efficiency Solution

The MAX20076 efficiency curves for the 3.3V and 5V versions, at 14V input, are shown in *Figure 50*. The devices' low RDS(ON) and integrated synchronous rectification MOSFETs produce high-efficiency operation. The efficiency remains high within a wide range of currents (from 1µA to 1.2A) thanks to automatic skip mode at light loads (blue and green portions of the curves in *Figure 50*) and constant frequency PWM operation at heavy loads (red and purple portions of the curves). Internal lossless current sensing across the MOSFETs' RDS(ON) further contributes to the solution's high efficiency. An external divider allows for an output voltage setting other than 3.3V and 5V.

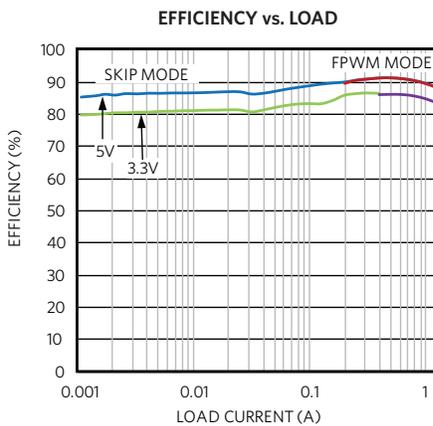


Figure 50. 3.3V and 5V Efficiency at 14V Input

Buck Converter Operation Above 3V

For output voltages above 3V, where the duty-cycle is sufficiently high, the current is sensed on the high-side MOSFET during its conduction (on) time. Accordingly, the device operates in peak current control mode (A and B versions) without hitting the minimum on-time (66ns), which is necessary to sense and process the peak current. Violation of the minimum on-time would force the device to operate in skip mode even at heavy loads.

Buck Converter Operation Below 3V

With output voltages below 3V and an input voltage above 12V, the minimum on-time of the high-side MOSFET is too low for proper current sensing and processing. On the other hand, the conduction time of the synchronous rectification MOSFET is close to 100%. In this case, it is convenient to sense and process the current on the low-side MOSFET (valley control mode). In this mode of operation, there is virtually no limit to the minimum on-time of the high-side MOSFET—other than the technology's speed limit. Very low duty cycles, down to 20ns on-time, are achieved with constant frequency operation (C versions). Competing devices that lack this feature are forced to buck the 12V down to an intermediate voltage and then cascade a second buck converter down to the final V_{OUT} at greater financial cost and loss of efficiency.

Small Size

The small (3mm x 3mm) 12-pin TDFN, side-wettable package with an exposed pad, along with its small BOM, greatly reduces the PCB size. The footprint of the switching regulator, including active and passive components, occupies only 16.6mm x 9.3mm as shown in Figure 51.

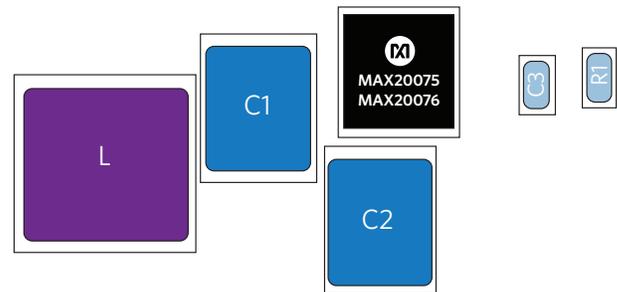


Figure 51. Small PCB Footprint 16.6mm x 9.3mm (154mm²)

Modes of Operation

To accommodate the various modes of operation, the two devices are available in three versions:

A = Fixed 5V output or 3V to 10V external resistor-divider (peak control).

B = Fixed 3.3V output or 3V to 10V external resistor-divider (peak control).

C = 1V to 3V external resistor-divider (valley control).

Conclusion

We have discussed the importance of low I_Q , low noise, and high efficiency in automotive ECUs. The MAX20075 (600mA) and MAX20076 (1.2A) buck converters operate above a 3V output and, when used with the fixed output setting (3.3V or 5V), have the lowest possible quiescent current. Alternatively, an external resistor-divider provides flexibility over the output voltage setting.

Each device offers a third version which operates with very low on-time in FPWM mode for output voltages below 3V, making them particularly effective in low-noise applications where constant frequency above the AM band at any load is required. In low duty-cycle applications, they provide single-stage buck conversion with excellent efficiency compared to competitive two-stage solutions.

Power Summary

Table 3 is a summary of power management products sorted by application for ADAS. **Figure 52** shows the Maxim power solutions for ADAS applications.

Table 3. Power Management for ADAS

Application	Products
Remote Camera Module	MAX20019 / MAX20020 Dual-Buck Converters
Camera ECU Front-End	MAX20087 Camera Protector
Camera ECU	MAX20414 PMIC
Radar	MAX20014 PMIC MAX20075 / MAX20076 Buck Converters
Cluster ECU Front-End	MAX20075 / MAX20076 Buck Converters MAX20098 Buck Controller MAX20034 Two-Phase Buck Controller
Cluster ECU	MAX20416 PMIC
Headlight ECU	MAX20078 LED Buck Controller MAX16990 / MAX16992 Boost Controllers MAX20053 Buck Converter
IR DMS	MAX20053 Buck Converter
Ideal Diode	MAX16141 MAX16126 / MAX16127

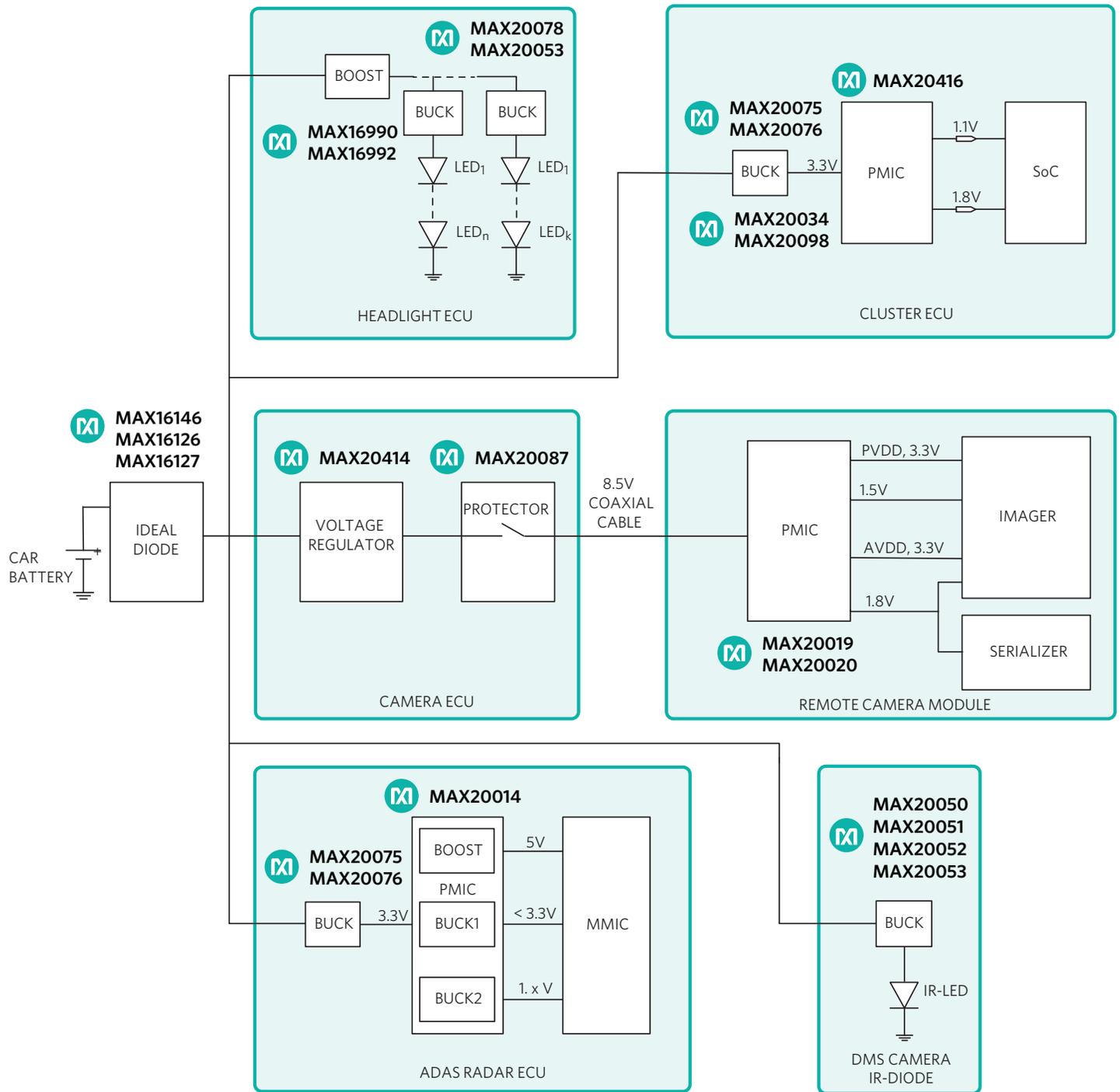


Figure 52. ADAS Power Products by Application

Case Study VI: Automotive-Grade Supervisory Solutions for ADAS

Routing the Journey to Functional Safety

With the increase of electronics in cars and the deployment of electrical/electronic functions in vehicles, functional safety is becoming a top consideration when developing for ADAS. ADAS, prevalent in consumer cars, enables such features as automated parking, lane departure assistance, and collision avoidance systems. These systems require a large signal chain, incorporating power, sensors, and intelligence resulting in a final action that the car executes.

ISO-26262 is one regulation that drives the requirements for functional safety, addressing possible hazards caused by malfunctioning behavior of electrical safety-related systems, including the interaction of these systems. The level of functional safety required for a system is categorized by the system's ASIL (Automotive Safety Integrity Level) rating. ASIL ratings range from level A to level D, with level D requiring the most robust system. A system's ASIL rating is determined by the severity of the potential injury, the controllability of the failure, and the exposure to risks if a failure occurs.

There are two ways to create an ASIL-compliant system. The first method is to use integrated circuits (ICs) that are ASIL-compliant themselves, which integrates performance analysis. The second method is to use supervisory circuitry to provide the detection, diagnosis, and validation required to make the system compliant. *Figure 53* graphically displays these two concepts to achieve an ASIL-D system, where the outer bubble represents the full system and the inner shapes represent individual ICs.

One Supervisor to Rule Them All

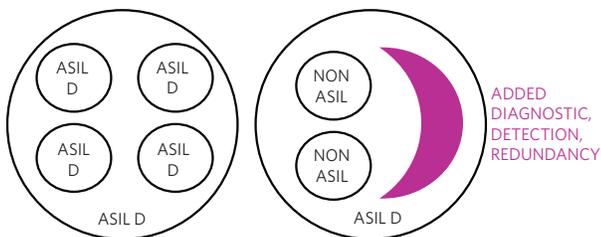


Figure 53. Two Methods to Create an ASIL D-Compliant System: Implementation of ASIL D-Compliant ICs (left); Implementation of Non-Compliant ICs with Additional Supervisory Circuits (right)

ADAS designs require both voltage monitoring and execution monitoring of microcontroller or SoCs (system-on-chips) to ensure the intelligence of the system makes coherent decisions. Often, an integrated solution that offers both features is the best architecture to decrease solution size. This is especially true for a centralized SoC that controls the peripheral circuitry and requires several voltage rails to properly operate.

The central SoC performs several complex algorithms to translate sensor data into a logic response, necessitating a watchdog (WD) IC to ensure proper execution. These complex algorithms require the integration of several functional blocks within the SoC that require different voltage rails to properly operate including—the main processor peripheral voltage, processor core, memory, and any other references needed for the internal architecture such as ADCs or DACs. Besides the main SoC, there are several microcontrollers throughout the system controlling the sensor data acquisition and actuation response, which requires additional monitoring.

The **MAX6746** provides a single-chip solution that integrates windowed watchdog (WD) and undervoltage monitoring to ensure the microcontroller is properly operating. To dive deeper into the individual functionality of the voltage supervision and WD, the stand-alone IC implementation of these functions is discussed.

Make It Right, Keep Tolerance Tight

SoCs require several different voltage rails to power analog and digital circuitry within the SoC. A few standard rail values are 1.8V, 3.3V, and 5V. It is important to ensure the rails stay within their proper operating range, commonly called the window voltage and defined in the datasheet as the recommended voltage operation range.

Most voltage supervisors use a percentage of the nominal reference voltage to create their undervoltage (UV) threshold, representing the lower limit of the window voltage; and their overvoltage (OV) threshold, representing the upper limit of the window voltage. They can also include hysteresis at the window thresholds to avoid noise-causing multiple transitions or fault conditions to be registered. One example of this functionality presents itself in the **MAX16132**. The MAX16132 has a factory-trimmed reference voltage at 1% initial accuracy to set the nominal reference voltage. It provides the window voltage threshold values ranging from $\pm 4\%$ to $\pm 11\%$, also with a 1% accuracy. The hysteresis for the threshold values can equal 0.25% or 0.50%. *Figure 54* displays the functional block diagram of the MAX16132.

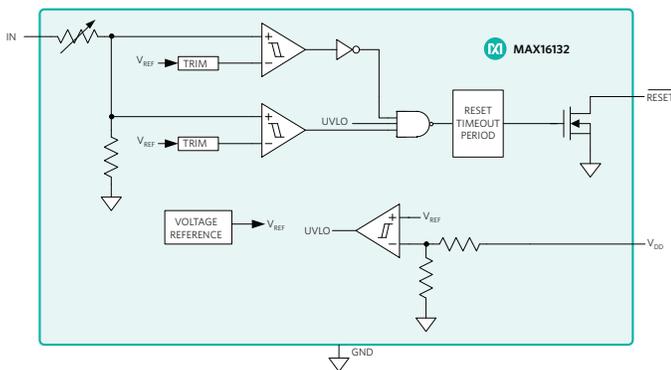


Figure 54. MAX16132 Functional Block Diagram

It is recommended to use a voltage supervisor with accuracy confined to a maximum of 1% for each of its features. This maximizes the use of the recommended operating voltage. For example, an ideal scenario would include a system with a 3.3V nominal supply voltage and a minimum voltage of 3V. The MAX16132, with a 3.3V nominal monitoring voltage and a -8% UV percentage provides a nominal UV reset value of 3.036V with a worst-case condition of 3.005V. This enables almost the complete range of recommended operation.

It is important to monitor all rails for UV and OV conditions to ensure proper operation since SoCs have several rails, which can cause part of the IC to incorrectly operate while the rest of the IC is in normal operation. For example, a UV event could cause volatile RAM memory corruption and result in inaccurate data retrieval for computations. OV events are equally important to track because they can cause damaging surges to the IC. Some applications even activate redundant circuitry once an OV event has taken place.

Voltage monitoring only tackles half of the problem to ensure a robust and safe system architecture. Execution monitoring is the second half of the equation to ensure functional safety.

Too Slow, Too Fast, Just Right

Watchdog (WD) timers are ICs that expect a periodic signal from a microcontroller or SoC in a specific timeframe to ensure the IC is correctly operating. The most basic WD expects a periodic pulse on its watchdog input (WDI) pin within a maximum timeframe to ensure the IC is executing properly. If the SoC misses a pulse, the WD issues a reset to put the SoC back into a known state. The **MAX6369** provides a great example of this functionality in a small SOT23 package.

The first WDs only checked to ensure the microcontroller did not get hung-up in the program. Newer WDs implement windowed timing requirements like the previous windowed

voltage discussed for voltage supervision. A windowed WD requires that the periodic pulse from the microcontroller is confined within a specific operating window. Having a minimum period for execution ensures that the microcontroller is not skipping execution steps within the program. This is equally as important as checking if the microcontroller gets hung-up.

Imagine if a calculation for braking was skipped in an avoidance collision system, creating a potentially life-threatening condition for the passengers. The MAX6746 is an IC that implements a windowed WD timer and provides a complete solution for adding detection and diagnostics to a system.

Windowed WDs are quickly becoming a requirement in safety-related systems to ensure the microcontroller is executing all steps and not getting caught in a loop. These WDs are specifically preferred in systems where the arithmetic logic unit (ALU) is heavily used. Traditional WDs that ensure the microcontrollers do not stall in their programs are great solutions for most general-purpose applications that pertain to non-safety-related application circuitry. No matter what the application, it is important to include a WD in the system to ensure the microcontroller is operating properly.

Market-Ready Supervisors

Voltage and execution supervising play a critical role in the functional safety for ADAS applications. Maxim provides a complete portfolio of stand-alone and integrated solutions for every safety level and application requirement. See the **Automotive-Grade Supervisory Products table** for automotive-grade supervisory products.

Summary

ADAS technologies have the potential to improve driver safety and comfort, and to reduce car accidents and casualties. The adoption of ADAS technologies creates challenges in electronic solution size, safety, and reliability. For each challenge, we showed examples of how power management can effectively help users realize ADAS systems. For increased miniaturization, we proposed highly integrated solutions for the remote camera module, as well as camera, radar, and cluster ECUs. For better safety and reliability, we proposed solutions for lighting ECU front-ends, infrared, and radar applications. Finally, for safety modules, we highlighted the availability of ASIL-qualified ICs and introduced a family of supervisory ICs that provide additional layers of safety. These power management and supervisory solutions overcome the critical challenges faced by today's ADAS implementations.

Product Selector Tables

ADAS Power Management Selector Guide

Part Number	Description	I _{OUT} (A)	V _{IN} (V)		V _{OUT} (V)		Package Type
		Max	Min	Max	Min	Max	
Buck (Step-Down) Converters/Controllers							
MAX20098	Versatile 36V 2MHz Buck Controller with 3.5μA I _Q	15	3.5	42	1	10	TQFN-CU-16
MAX20034	2.2MHz, 36V, Dual Buck with 17μA Quiescent Current	30	3.5	42	1	10	TQFN-CU-28
MAX20075	2.1MHz, High-Voltage, 0.6A Mini-Buck Converter	0.6	3.5	40	1	10	TDFN-CU-12
MAX20076	2.1MHz, High-Voltage, 1.2A Mini-Buck Converter	1.2	3.5	40	1	10	TDFN-CU-12
MAX20019	3.2MHz, 500mA Dual Step-Down Converter for Automotive Cameras	0.5	3.5	17	1	5	TDFN-10
MAX20020	3.2MHz, 500mA Dual Step-Down Converter for Automotive Cameras	0.5	3.5	17	1	5	TDFN-10
MAX20073	2.1MHz, Low-Voltage, 2A Mini-Buck Converter	2	2.7	6	0.5	3.8	TQFN-10
MAX20012B	2.2MHz, Automotive Low-Voltage Two-Channel Step-Down Controller	24	3	5.5	0.5	1.5875	TQFN-32
MAX20416	2.2MHz Dual-Output, Low-Voltage Step-Down Converter	3	3	5.5	0.8	3.8	TQFN-24
Boost (Step-Up)/SEPIC Controllers							
MAX16990	36V, 2.5MHz Automotive Boost/SEPIC Controller	6	2.5	42	5	36	μMAX [®] -EP-10 TQFN-12
MAX16992	36V, 2.5MHz Automotive Boost/SEPIC Controller	6	2.5	42	5	36	μMAX-EP-10 TQFN-12
PMICs							
MAX20014	2.2MHz Sync Boost and Dual Step-Down Converter	3	3	5.5	0.8	3.8	TQFN-24
MAX20414	2.2MHz Sync Boost and Step-Down Converter	3	3	5.5	0.8	8.5	TQFN-24
LED Drivers							
MAX20053	2A Synchronous Buck LED Driver with Integrated MOSFETs	2	4.5	65			TDFN-12 TSSOP-14
MAX20078	Synchronous Buck, High-Brightness LED Controller	10mA	4.5	65			TQFN-16 SSOP-16
Protection Circuits							
MAX16127	Load-Dump/Reverse-Voltage Protection Circuit		36	90			TQFN-12
MAX16141	3.5V to 36V Ideal Diode Controller with Voltage and Current Circuit Breaker		3.5	36			TQFN-16
MAX20087	Dual/Quad Camera Power Protector	0.6	3	5.5			SW TQFN-20

Automotive-Grade Supervisory Products

Part Number	Functionality	Description
MAX6369/ MAX6374	Watchdog	Pin-Selectable Watchdog Timer with Open-Drain Output and Startup Delay under 60s
MAX16132/ MAX16133/ MAX16134/ MAX16135	Voltage Monitoring	Low-Voltage, 1% Accurate Voltage Monitor
MAX803	Voltage Monitoring	3-Pin μ P Reset Circuit with Open-Drain/RESET
MAX6414	Voltage Monitoring	Low-Power, Single-Voltage μ P Supervisor with Capacitor-Adjustable Reset Timeout, Manual Reset, and Open-Drain /RESET
MAX6340	Voltage Monitoring	Low-Power, SOT23 μ P Reset Circuit with Capacitor-Adjustable Reset Timeout and Open-Drain /RESET
MAX6316/ MAX6320	Watchdog + Voltage Monitoring	5-Pin μ P Supervisory Circuit with Watchdog, Manual RESET, and Active-Low Open-Drain RESET Output
MAX6746/ MAX6747/ MAX6750/ MAX6751/ MAX6752/ MAX6753	Watchdog + Voltage Monitoring	μ P Reset Circuit with Fixed Reset Threshold, Standard Watchdog Timer, Manual Reset, and Push-Pull /RESET
MAX6734	Watchdog + Voltage Monitoring	Triple-Voltage μ P Supervisory Circuit with Watchdog Input/Output, Manual Reset, and Open-Drain /RESET

Related Resources

White Papers

[Choosing the Right Automotive ICs for Next-Generation Vehicles](#)

[Balancing Power Supply Requirements in ADAS Applications](#)

Design Guides

[Gigabit Multimedia Serial Links \(GMSL\) for ADAS Design Guide](#)

Blogs

[Choosing the Right Power Management ICs For Automotive Designs](#)

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Design Solutions

[Achieve Superior Automotive Exterior Lighting with a High-Power Buck LED Controller](#)

[Improve Your Automotive ECU Design with a Low-I_Q Buck Converter](#)

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Learn more

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www.maximintegrated.com/adas-power

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