

AUTOMOBILE ACCESSORIES AND CONTROL ELECTRONICS BENEFIT FROM POWER-MANAGEMENT SCHEMES TO PREVENT DEAD BATTERIES AND GAS GUZZLING. LOW-POWER ELECTRONIC SUBSYSTEMS ARE ESPECIALLY IMPORTANT FOR THE NEXT GENERATION OF ELECTRIC CARS AND PLUG-IN ELECTRIC VEHICLES.

The ideal gas-powered car moves its driver and passengers from Point A to Point B in comfort while sipping gas and producing next to no harmful emissions. However, car buyers have sharply inflated their definition of “comfort” to the point at

which many owners now expect their cars to provide satellite navigation, security, climate control, an Internet interface, and even beverage refrigeration. This escalation in features has caused a corresponding increase in the car-battery load when the engine is off and the car’s electronics are in a sleep state. Designers of electronics accessories for cars have to balance the power needs of car features and accessories

BY MARGERY CONNER • TECHNICAL EDITOR

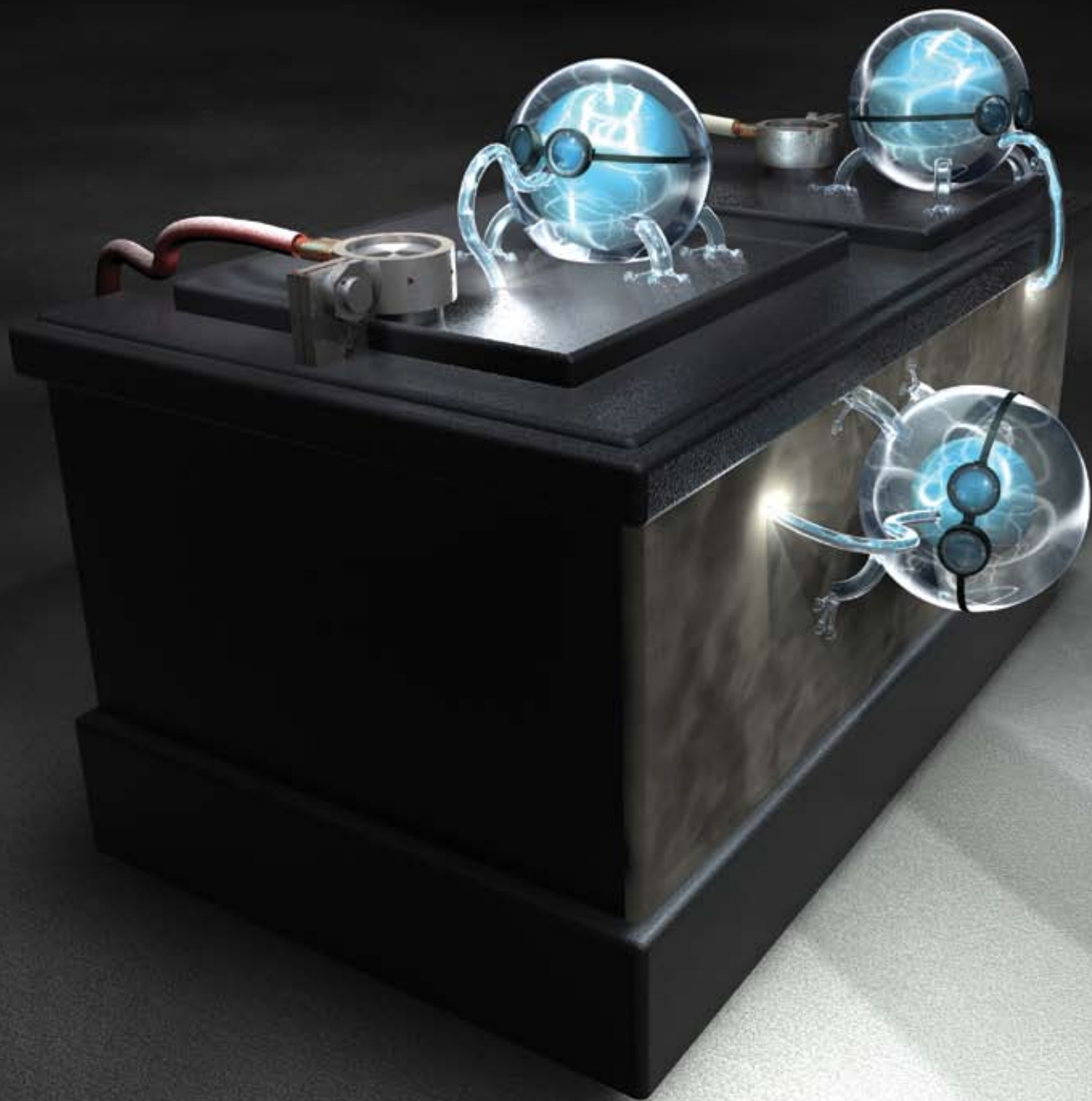


AUTOMOBILE ELECTRONICS SEEK TO PLUG POWER LEAKS

with the finite power that a car battery contains when in a sleep state. In addition, rising gas prices make fuel economy increasingly important to consumers, causing automobile OEMs to turn to complex but efficient electronic-control systems for subsystems such as fuel delivery and air conditioning.

Back when car electronics were primitive and gas was cheap, there was little incentive to conserve the power that the car electronics used. However, designers of automobile accessories and subsystems must make designs that consume as little power as possible because today’s cars almost universally rely on a network such as the CAN (controller-area-network) bus and have a stringent sleep-state-power budget for electronic subsystems. Sleep-state-power budgeting prevents, for example, a weary traveler returning to the airport parking lot after a two-week trip from finding that the car’s always-on electronics had drained the battery in his absence.

An air bag is an example of a system that turns completely off when the car is parked; there’s no need for air-bag deployment in a parked car. Other subsystems that still have a function when the car is parked, such as a key-



less-entry or alarm system, will remain on but in a sleep state, drawing a small “keep-alive” current. They are on a direct battery feed. Car OEMs define the car platform’s power distribution within the network architecture so that power is available to always-on systems, while other systems are asleep, waiting for a wake-up signal from the network. Although companies do not make public the sleep-state-power budgets for the accessories and subsystems, Tony Richardson, product-marketing manager of the power-products group at Linear Technology, estimates that [a constant drain of] 20 to 50 mA per day is a good range.

Network architectures and sleep-state power budgets have all but eliminated the dead-battery-at-the-airport scenario for cars with healthy batteries. However, after-market add-on electronics can still pull a battery down. After-market electronics can’t tap directly into the network and rely on a power connector, such as the cigarette lighter, for power.

“Each OEM’s messaging strategy is tightly controlled, and they don’t open it up to after-market guys,” says Kev-

AT A GLANCE

▣ The sleep-state-power budget allows for less than 50 mA per day; the power regulator alone should have a quiescent current of less than 50 μ A.

▣ Modern networked cars prevent their electronics from draining a car battery when the ignition is off, but after-market electronics can still suck a battery dry.

▣ The easiest way to increase a car’s fuel economy is still to reduce its engine size.

in Anderson, systems and applications manager for the analog-products division of Freescale. “For purposes of data integrity, it’s not an open system.”

Even when the car’s engine is running and electrical power is plentiful, electronics accessories and subsystems still need to conserve power to manage car thermal hot spots and, increasingly, for fuel economy (see sidebar “Parasitic power losses”). Semiconductor and IC manufacturers continue to move into the automobile by adding low-power

features and intelligence to even relatively simple electronics.

INTELLIGENT SWITCHES

Solid-state devices are replacing relays, once common automotive-load switches, for increased reliability as well as lower on-resistance. Although a relay might have a resistance of 25 to 100 m Ω , an SSR’s (solid-state relay’s) resistance can be just 2 m Ω , roughly equivalent to a few feet of standard-gauge copper wire. Low resistance is important in subsystems such as the engine starter, in which current can reach 700A. Other circuits’ currents vary even as they remain on. For example, when an incandescent headlight first turns on, the bulb element is cold and allows a surge of initial inrush current of 100 to 150A for 20 to 50 msec. As the current heats the bulb, however, the resistance increases, and the current flow drops to 5 to 40A, depending on the bulb size. Intelligent SSRs, such as Freescale’s eXtreme Switch product family, allow for the large initial inrush current with a variable setpoint. As the bulb heats up and the resistance changes, the setpoint moves to a new threshold for the lower current. However, if the current suddenly increases at that point, indicating a short circuit, the chip acts as a fuse and turns off, protecting both the switch and the load. These intelligent switches, in addition to being more power-efficient, also increase reliability and lower BOM (bill-of-materials) costs.

Headlights are second only to a car’s HVAC (heating/ventilation/air-condition) system as an electrical-power load. HB (high-brightness) LEDs (light-emitting diodes) are finding use in city-lighting systems due to their lower power requirements, durability, and long lifetimes, and these same features will probably make them standard features in both interior and exterior lighting for some cars in the next few years. Taillights and daytime running lights use them; Cadillac has announced that they will be available in the Escalade Platinum’s headlights this summer (Figure 1).

In addition to power efficiency, LED headlights also make it easier to put the light where the driver needs it. Current high-end cars feature electric-motor-driven steerable headlights that track the car’s path

PARASITIC POWER LOSSES

Where do car electronics fit in the big scheme of automobile-fuel economy? They are not too high on the list, as you can see from the US Department of Energy’s fuel-economy Web site (Reference A): Less than 13% of the energy from the fuel you put into your tank serves to actually move your car. You lose the rest of the energy to engine and driveline inefficiencies; idling; and accessories, such as air conditioning. Table A shows the overall breakdown.

This breakdown leaves you with 12.6% to drive the car down the road. Although some improve-

ments in fuel economy will come from aerodynamics and mechanical enhancements, there’s still room for improvement due to electronic controls. For example, using an integrated starter that turns the engine off at a stoplight and automatically restarts when you step on the gas can improve on that 17% you lose to idling.

REFERENCE

▣ Advanced Technologies and Energy Efficiency, US Environmental Protection Agency, www.fueleconomy.gov/feg/atv.

TABLE A BREAKDOWN OF AUTOMOBILE-FUEL USAGE

Car subsystem	Losses	Causes
Engine	62.4%	Engine friction, moving air, wasted heat
Standby/idle	17.2%	
Accessories	2.2%	For example, air conditioning
Driveline losses	5.6%	

around a turn. An array of LEDs that turn on and off to light the path can eliminate the need for less reliable tracking motors.

The main roadblock preventing solid-state lighting in cars is the cost. HB-LED-production numbers will have to grow to cause the price drop necessary to include them in Chevrolet models as well as Cadillacs. In addition, temperature changes strongly affect LED-light output, with output varying by as much as 50% over the automotive-temperature range of subfreezing temperatures in the winter to triple digits in the summer.

Headlight LEDs require sophisticated power-management ICs. "You don't just drive one LED in a headlight," explains Freescale's Anderson. "You drive multiple ones in strings, and their brightness must remain constant, while the car-battery voltage can range from 8 to 16V in normal-run conditions. You need a switching power supply that will create a constant output with a variable input. Plus, LEDs themselves are not the same brightness universally, and they also age with time, so you have to make adjustments for each LED to make sure you get a constant output."

HB LEDs in headlights are not the only subsystems that can justify the use of switching regulators in cars: Just about any module that the CAN bus controls can benefit from the high efficiency and variable output states of a switching regulator as opposed to the older and simpler but less efficient linear regulators. Although none of the car OEMs publish the power budget for modules the CAN bus connects, Richardson of Linear Technology says that a consensus exists among the OEMs that any power regulator to power the microprocessor in an end system needs a quiescent current in the sleep mode of less than 100 μA , giving the advantage to the more efficient switching regulators. For more on low-quiescent-current-switching design, see sidebar "Low-quiescent-current switchers target automotive-electronic design."

Virtually all electronics subsystems include processors, and some core-based processors can conserve power in their system-sleep state by lowering their voltage, frequency, or both (Reference 1). For example, Texas Instruments' ARM (www.arm.com)-based TMS470 family uses dynamic-voltage scaling, which al-

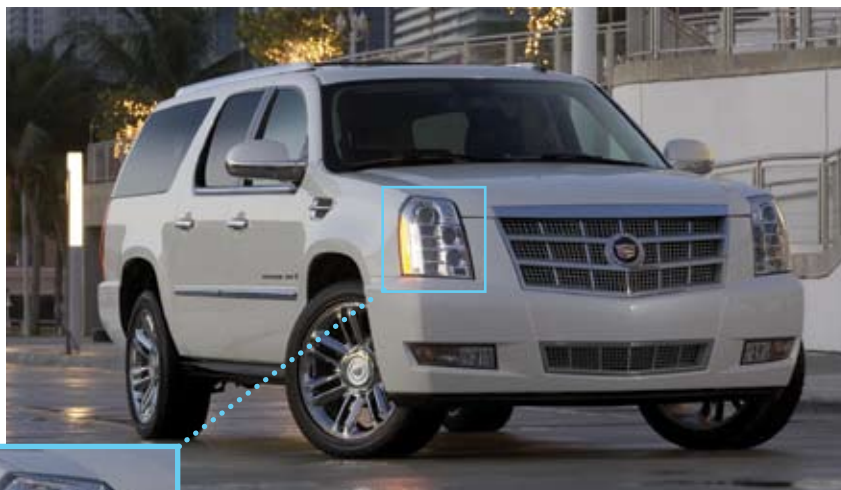


Figure 1 The Cadillac Escalade Platinum is one of the first production cars to use HB LEDs for headlights. LEDs also find use as indicators, taillights, and cabin lights.



lows you to drop the voltage from, say, a normal operating voltage of 1.2V to a sleep state of 1V, a corresponding current savings of 20%. Why not just completely turn off the processor? Even though the system is in a sleep state, it still must be able to respond to some simple commands, albeit at a reduced response rate.

Although such processor-based ICs have voltage management within the chip itself, these parts rely on external power-management parts to take the battery voltage, which is approximately 13V, down to the IC's input voltage range of 2 to 3V. These power-management parts for the automotive world face a tough set of specifications for designs

for future cars: They must drop their quiescent current from today's 100 μA to 30 to 50 μA to support the sleep-state-power budget for power-management chips. Plus, they need to work more closely with the CAN bus for system-wake-up commands. Expect to see power-management chips for the automotive market in the coming year begin to integrate CAN transceivers into the power-management and power-regulation chips. In addition, power-management ICs must keep the switching-circuit EMI (electromagnetic interference) from affecting the communication-transceiver portion. These new chips will face tough design criteria to meet the needs of automobile OEMs and module designers.

As electronic controls creep further into car design, their potential for increases in efficiency goes beyond power-regulation opportunities. A motor-driven compressor can more efficiently perform many functions that mechanical subsystems traditionally performed, such as the belt-drive compressor for air conditioning. Similarly, electric-motor-driven, variable-assist power steering can improve fuel economy by as much as 0.5 mpg in reducing parasitic losses common in belt-driven hydraulic systems. Ford has announced it will be making its six-speed automatic transmission standard in future cars. This transmission, which electronically shifts gears, is more fuel-efficient than current automatic or manual transmissions.

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LOW-QUIESCENT-CURRENT SWITCHERS TARGET AUTOMOTIVE-ELECTRONIC DESIGN

By Tony Armstrong, Linear Technology Corp

Modern automobiles continue to include increasingly complex electronic systems. Furthermore, the automotive environment continues to be harsh for any type of electronics. Wide operating-voltage requirements, large transient voltages, and large temperature excursions combine to make life tough on electronic systems. What's more, the performance requirements continue to become even tougher. Multiple supply voltages are necessary for different portions of the system. A typical navigation system can have six or more supplies, including 8.5, 5, 3.3, 2.5, 1.5, and 1.2V. At the same time, as the number of components increases, space requirements continue to shrink. Therefore, efficiency becomes more critical in space-constrained systems because of the space limitations and temperature requirements. At low output voltages and even with current levels above a few hundreds of milliamps, it becomes impractical to use a linear regulator to generate these system voltages. As a result, over the last several years, primarily due to thermal constraints, switching regulators have been replacing linear regulators. The benefits of a switcher, including the increased efficiency and smaller footprint, outweigh the additional complexity and EMI (electromagnetic-interference) considerations.

A switching regulator in an automotive environment needs a wide input-operating range; good efficiency across a wide load range; low quiescent current during normal operation, standby, and shutdown; low thermal resistance; and minimal noise and EMI emissions.

Any switching regulator would need specification to work over a wide input-voltage range of 3 to 60V and could find use in automotive systems capable of running on 14 or 42V. The 60V rating gives a good

margin for 14V systems that usually clamp at 36 to 40V. Furthermore, it allows you to use the device in future 42V systems. Therefore, you can easily upgrade a design for a 14V system for a 42V system without any significant redesign.

High-efficiency power conversion across a wide load range is essential in most automotive systems. As an example, you can expect power-conversion efficiency of around 85% for a 5V output over a 10 mA to 1.2A load range. At high currents, the internal switch needs good saturation—typically, 0.2Ω at 1A. To improve light-load efficiency, drive current is smaller or proportional to load current. Also, a bias pin, which the output can power, could supply power for the internal control circuitry, taking advantage of the power-conversion efficiency of a buck converter. The fact that this bias current draws from the output rather than the input decreases the input supply current for the control circuit by the ratio of the output voltage to the input voltage. For example, an output current of $100\mu\text{A}$ at 3.3V requires an average input current of only $30\mu\text{A}$ at 12V, minimizing the input current the control circuitry requires and increasing light-load efficiency.

Many applications in automotive systems require continuous power even when the car is parked. Examples include remote keyless entry, GPS (global-positioning-system)-location tracking, and alarm systems. A key requirement for these applications is low quiescent current. The device would run in normal continuous-switching mode until the output current drops below about 100 mA. Below this level, the switching regulator must skip pulses to maintain regulation. Between pulses, the regulator can go into a sleep mode in which only a portion of the internal circuitry receives power. At light load currents, a switching regulator

needs to automatically switch to a mode in which the quiescent current drops below $100\mu\text{A}$ for a 12 to 3.3V converter. The internal reference and power-good circuit remains active in sleep mode to monitor the output voltage. Quiescent current should be less than $1\mu\text{A}$ in shutdown.

Ideally, the junction-to-case thermal resistance should be low. If you expose the backside of the device to copper and solder it to the surface of the PCB (printed-circuit board), you can use the PCB to conduct heat away from the device. Four-layer boards with internal power planes that are common today can achieve thermal resistance of nearly $40^\circ\text{C}/\text{W}$. High-ambient-temperature applications with good thermal conduction to a metal housing can achieve thermal-resistance numbers approaching a typical junction-to-case number of $10^\circ\text{C}/\text{W}$, which helps to extend the useful operating-temperature range.

Although switching regulators generate more noise than linear regulators, their efficiency is far better. Noise and EMI levels have proved to be manageable in many sensitive applications as long as the switcher behaves predictably. A switching regulator switching at a constant frequency in normal mode and switching edges that are clean and predictable with no overshoot or high-frequency ringing minimize EMI. A small package and high operating frequency can provide a small, tight layout, minimizing EMI radiation. Furthermore, if you can use the regulator with low ESR (equivalent-series-resistance) ceramic capacitors, you can minimize both input- and output-voltage ripple, which are additional sources of noise in the system.

Author's biography

Tony Armstrong is product-marketing manager for the power-products group at Linear Technology.

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There's also opportunity for power savings in the scheme by which the alternator charges the battery itself. If it's a nice day that requires no air conditioning, heating, or lights, the car requires less electrical power and puts a smaller load on the alternator. In most vehicles, however, the alternator provides an output to constantly charge the battery and is sized to provide a maximum load—for example, on a winter night when it's snowing, and the heater and lights are on. A more efficient alternator will vary its speed based on the load.

ELECTRIC CARS AND PHEVs

EVs (electric vehicles) and PHEVs (plug-in hybrid electric vehicles) operating in their battery-only mode require the most power-miserly electronic subsystems (**Reference 2**). General Motors Vice President of Engineering Bob Lutz has talked about the importance of power efficiency in electronic accessories—even the mundane windshield wipers—for the Chevy Volt PHEV because any subsystem that draws on the battery reduces the range of the Volt in its battery-only mode, currently about 40 miles (**Reference 3**).

Tesla Motors is developing a high-end lithium-ion-battery-powered EV with a 240-mile range. As with conventional cars, cabin cooling is the largest accessory load for an EV, and Dan Adams, senior mechanical engineer for systems and integration at Tesla, estimates that it commonly takes about 2 kW of power in an EV. “Cabin heating comes next in power consumption, but for an ICE [internal-combustion-engine]-powered car, waste energy required to cool the engine is enough to heat the cabin and thus is ‘free,’” he says. Because the electric power train in an EV is efficient, it takes awhile to heat, and the waste-heat power is much lower than the power available with a gas engine. The 3 kW to conventionally heat a cabin would be a serious drain on the battery's energy. EV manufacturers, such as Tesla, are working on alternative methods for cabin heating, such as relying on seat heaters for localized heat, as well as PTC (positive-temperature-coefficient) heaters for general cabin heating.

Scott Brenneman, release engineer for vehicle electrics at Tesla, comments on how running accessories, such as a heater

or a radio, affect the range. “In general, some simple math shows the impact on the range,” he says. “In rough terms, a given load would have a quantifiable effect on a 50-kWhr battery pack, assuming you also knew the other loads. Back of the envelope, let's say the range over a given course is 240 miles, driven at an average speed of 30 mph, for a total time of eight hours. I suspect that the effect of most electrical subsystems on range is small except for a few items, such as the HVAC components. For instance, a 1-kW load running half the time would consume 4 kWhr, or $4/50=8\%$ of the range. I think this is an extreme case, since 1 kW of heating or cooling is a lot. Typical 12V loads, such as exterior lights, are less than 0.2 kW in this scenario and thus would reduce range by about 1.5%.”

Adams provides some perspective on the quest to eke out relatively small amounts of power efficiency in the ubiquitous automobile. “Cabin comfort [and car transportation in general] requires great quantities of energy compared to the basic scale of human energy needs,” he says. “Thus, while a human can ride a bike and transport [himself] using only a fraction of a horsepower, a car driving 20 mph can easily consume 10 kW with another 2.5 kW for HVAC if cooling is on.” As a dedicated biker, however, Adams is a bit biased. **EDN**

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You can reach
Technical Editor
Margery Conner
at 1-805-461-8242
and mconner@connerbase.com.

