System power architectures in body control modules

Arun T. Vemuri
General Manager, Automotive Body Electronics and Lighting
Texas Instruments

Donovan Porter
Systems Engineer, Automotive Body Electronics and Lighting
Texas Instruments
Functions of comfort and convenience available in all modern vehicles today (and in the foreseeable future) rely on body control modules (BCMs). BCMs work behind the scenes to operate headlights, rear lights, interior ambient lights, windshield wipers and more.

Both the quantity of BCMs in a car and the number of comfort and convenience loads that each BCM controls vary across vehicle models. From a BCM that only handles lighting functions to a BCM that includes gateway functionality and car-access support, the number of BCMs and their complexity depend on the underlying architecture of the vehicle body electronics.

BCM designs are also rapidly evolving. For example, junction boxes (also known as power distribution boxes), which distribute power to various loads using relays, are either being integrated into BCMs or converted to BCM-like modules to distribute power through semiconductor switches. More driver inputs and sensors are being connected to BCMs as the number of comfort and convenience features increases. And as the number of dedicated load-control modules (such as those for roof motor control) increases, BCM networking requirements also increase.

**Figure 1** shows a block diagram of a BCM with sensor and switch interfaces, communication interfaces and load driver blocks. In **Figure 1**, the microcontroller (MCU) block is a generic representation of an embedded digital processor with different peripherals.

With the varying complexity of BCMs, the number of active semiconductor components in the BCM also varies. And an active semiconductor device needs a voltage supply (or power) to operate.

A simple BCM that supports only a few features could have just a couple of load drivers and a networking interface, while a complex BCM that controls multiple features could include semiconductor devices such as references, operational amplifiers, multiplexers, multiple-switch detection interfaces, high-side switches and light emitting diode (LED) drivers.

All active semiconductor devices in a BCM with varying complexities of functionality have one thing in common – they all need electrical power, which is provided by power-management semiconductor components.

The complexity of the power-management architecture depends on the complexity of the BCM. A simple BCM could be powered by a single low-dropout regulator (LDO), while a more complex BCM could be powered by multiple multistage switching regulators. The BCM ultimately derives the electrical power needed to operate from the automotive 12-V battery.
In other words, the power-management devices in the BCM take the 12-V input from the automotive 12-V battery and generate the voltage needed for the different semiconductor devices in the BCM.

These voltages typically range from 1.2 V to 5 V. Also, regardless of power architecture complexity, there is at least one power-management device connected to the 12-V battery-supply pin of the BCM.

In this paper, we'll discuss the various power architecture used in modern-day BCMs.

**Powering the BCM**

**Figure 2** is a simple block diagram of the power-management.

The automotive 12-V battery is not a clean source of power to the various control modules in a vehicle, including the BCM. The 12-V battery voltage not only has a wide operating voltage range, but also has including the BCM. The 12-V battery voltage not only has a wide operating voltage range, but also has voltage transients. The power-management device connected to the 12-V battery supply in the BCM not only has to provide power to active semiconductor devices in the BCM under these 12 V supply variations, but also cannot get damaged.
The number of output voltage rails and the voltage and current in each rail depend on active semiconductor devices in the BCM. Furthermore, if the BCM generates power for a sensor that is off-board from the BCM, the power-management device generating that power has to be robust against faults.

**Power-management architectures in BCMs**

To power BCMs, you need to know two things:

- Through what battery conditions does the BCM need to operate?
- What functions does the BCM integrate or control?

Answering these questions will help determine the best power-management architecture for powering various semiconductor integrated circuits (ICs) on the BCM’s printed circuit board (PCB).

Deciding the battery conditions through which the BCM needs to operate depends on the overall vehicle body architecture and what loads the BCM is driving. Furthermore, if the BCM integrates various functions, such as passive-entry passive-start (PEPS), remote keyless entry (RKE) and/or tire-pressure monitoring systems (TPMSs), the number of ICs on the BCM PCB will increase along with the MCU processing requirements. Therefore, the total system power requirements increase.

**LDO power architecture**

The simplest BCM power management system is an all-LDO power architecture. BCM designs that use an all-LDO power architecture do not generally have to operate through engine cold-crank or start/stop conditions.

Furthermore, a BCM with an all-LDO power architecture does not typically integrate additional functions such as PEPS, RKE, TPMSs and/or gateway functionality. These BCMs implement fewer communication transceivers such as Controller Area Network (CAN) and Local Interconnect Network (LIN), along with a less power-hungry MCU. Let’s classify these BCMs as a base BCM, which is the least complicated BCM variant.

An LDO-only architecture uses wide-input voltage LDOs for all necessary power rails. Figure 3 shows the simplicity of an LDO power architecture. Adding additional LDOs can provide various voltage rails. Each LDO lays out easily on the PCB and all LDOs require only a pair of capacitors and possibly a pair of resistors.

In spite of the LDO architecture’s benefits – including fewer electromagnetic interference (EMI) challenges, a small form factor and simple implementation – there are several other factors to consider. LDOs do not have very good power efficiency, which can lead to thermal constraints caused by power dissipation within the device. When designing a BCM power architecture that requires around 400 mA or more, an LDO may not be the best option due
to thermal constraints. In addition, LDOs cannot operate through cold-crank or start/stop conditions and provide the necessary 5-V CAN rail due to the voltage drop across the LDO and the reverse battery-protection diode.

**First-stage buck converter/controller power architecture**

**Buck-to-LDO/buck**

The switching buck regulator-to-LDO/buck regulator power management system is a flexible dual-stage power architecture that implements a first-stage buck converter/controller followed by a second-stage step-down converter (LDO or buck). The second-stage buck/LDO can be a single LDO, a single buck converter/controller or a combination of each type. A single wide-input-voltage buck converter/controller provides the first voltage rail, followed by a low-input-voltage LDO/buck to provide a lower voltage rail to power the MCU and other devices.

BCMs with a buck-to-DC/DC power architecture may have additional functionality integrated into the BCM, requiring more current on one or more voltage rails. BCMs that implement this power architecture could be base BCMs or multifunction BCMs with or without gateway functionality.

**Figure 4** shows the buck-to-DC/DC power architecture. It’s possible to use this architecture in the most complex BCMs simply by adding additional LDOs and/or buck converters off the rail of the first-stage buck. Select the wide-input-voltage buck to provide the highest power voltage rail in the system (for a buck-to-LDO/buck architecture, typically 5 V). This improves overall power efficiency, as the highest current rail will only be converted once instead of twice, reducing both conduction and switching losses.

As long as the first-stage buck meets the total BCM power requirements, there is no issue in adding additional DC/DC regulators off the first-stage buck regulator rail. From a system perspective, you can add additional communication transceivers to the BCM, including Ethernet, along with various radio-frequency ICs and higher-performance MCUs. You have various options to meet your specific BCM requirements.

**Buck-to-boost power architecture**

The buck-to-boost power architecture is very similar to the dual-stage buck regulator to LDO/buck regulator power architecture, with two main differences:

- As stated in the name, the first stage is a wide input-voltage buck followed by a low-input-voltage boost.
- The buck provides a lower voltage rail than in the previous first-stage buck power architecture where there is no boost. This allows BCMs that implement the buck-to-boost architecture to operate through engine start/stop and, in some cases, even cold-crack (depending on the original equipment manufacturer’s (OEM) minimum input voltage requirement).

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*Figure 4. Buck-to-LDO/buck power architecture.*
A BCM that implements this power architecture can use an MCU with higher power requirements along with multiple CAN and LIN transceivers or even base station ICs for PEPS/RKE functions. Therefore, the buck-to-boost power architecture fits all types of BCMs.

In Figure 5, notice that you can add another LDO or buck converter at the output of the first-stage buck regulator. Overall system power efficiency increases from the use of two switch-mode power-supply ICs. In addition, the buck-to-boost power architecture gives you more flexibility for a customized power architecture that fits the exact BCM power needs.

You can select the wide-input-voltage buck and low-input-voltage boost based on the system’s specific current requirements.

Using only one wide-input-voltage buck followed by low-input-voltage DC/DC regulators optimizes the power architecture cost. It’s also possible to add low-input-voltage LDOs or DC/DC regulators to the second-stage output rails if you need lower voltage rails, providing solutions for BCMs with various voltage rail or high power requirements.

Although the first-stage buck architectures have the benefits of improved power efficiency and design flexibility, there are trade-offs:

- All switching DC/DC converters/controllers require additional filtering to improve electromagnetic compatibility (EMC), and you have to carefully lay out the PCB to improve the BCM’s EMC.
- Adding DC/DC regulators increases the total bill-of-materials (BOM) count. You’ll need additional capacitors and inductors because of the EMI filter (of the first-stage buck) and the DC/DC’s external components. From an input-voltage perspective, the buck-to-LDO/buck power architecture cannot operate through engine cold crank and, in some cases, start/stop conditions. However, the buck-to-boost power architecture guarantees operation through start/stop and possibly cold crank.

**Single/dual-stage buck-boost power architecture**

A buck-boost power management system is a simple and effective BCM power architecture. Given the buck-boost’s nature, the system can operate through start/stop and even cold-crank input-voltage requirements. BCMs that could implement a buck-boost power architecture are typically simpler systems that require around 1 A-1.5 A and need to operate through cold crank. This architecture would be a good fit for stand-alone BCMs or even BCMs with gateway functionality.

Figure 6 illustrates the simplicity of the buck-boost power architecture. Notice that an additional LDO can provide lower voltage rails for the system. Only a single inductor and several capacitors are required around the IC, thus reducing the PCB footprint. Additionally, buck-boosts offer good power efficiency.
The buck-boost alone could provide power to the entire BCM, including the CAN and LIN transceivers and the MCU, in a simple, small footprint.

Although the buck-boost power architecture is simple to implement and has good power efficiency, there are some challenges to consider:

- As with all switch-mode DC/DC regulators, EMC will add to the system BOM cost.
- From an overall power architecture design viewpoint, there is less flexibility when designing with a buck-boost power architecture. Other power architectures allow for a specific combination of bucks, boosts or LDOs to tightly fit the system’s current requirements. With a buck-boost, the designer’s choices are limited.

**Single-/dual-stage SEPIC power architecture**

The single-ended primary inductor converter (SEPIC) power management system, as shown in Figure 7, is another effective and straightforward power architecture that enables BCMs to operate through cold-crank and start/stop conditions.

The advantage of the SEPIC power architecture over a buck-boost topology is that it requires only a single boost controller, reducing IC cost. A SEPIC architecture is great for any BCM that requires operating through even the worst input-voltage conditions.

A SEPIC converter uses a single boost controller, with additional low-input voltage bucks or LDOs added off the SEPIC’s voltage rail if needed. Because this architecture uses a boost controller, an external field-effect transistor (FET), diode and coupled inductor (or two individual inductors) are required. You can design the SEPIC converter to handle various power ranges and output voltages depending on your system requirements.

Although the SEPIC power architecture has the advantage of operating through cold-crank and start/stop and reduces IC cost, there are several trade-offs to consider. The SEPIC converter footprint will be large due to the external inductors, FET and diode. SEPIC converters are also less efficient than buck-boost converters because of their increased switching and conduction losses.

![Figure 6. Buck-boost power architecture.](image)

![Figure 7. SEPIC power architecture.](image)
First-stage boost converter/controller power architecture

First-stage boost or pre-boost power architecture are used in BCMs to specifically operate through engine cold-crank and start/stop conditions. Pre-boosts are followed by an LDO or buck-power power architecture. All BCM variants could implement a pre-boost architecture, but those that require a pre-boost will likely control or implement a vehicle function that requires operating through cold-crank battery conditions.

**Figure 8** shows the pre-boost power architecture. Although this power architecture implements a wide-input-voltage boost, the power stage that follows the boost must have wide-input-voltage capabilities. This is because the boost will only operate when the battery voltage drops below the specified boost output voltage. You’ll need to select the pre-boost output voltage or intermediate voltage to optimize the efficiency of the downstream DC/DC regulators.

Unlike the first-stage buck power trees, all DC/DC regulators connected to the boost output voltage have wide-input-voltage requirements. Furthermore, adding another DC/DC regulator increases the power tree’s PCB footprint, requiring yet another inductor and a set of input and output capacitors.

Lastly, as with all switching DC/DC regulators, EMC becomes a main concern. Therefore, pre-boost implementations are implemented only when it is absolutely necessary to operate at the lowest cold-crank requirements.

**Figure 8.** First-stage boost power architecture.
**A note about SBCs**

A system basis chip (SBC) is a semiconductor device that has both power-management and networking functions. Since BCMs need both, their designs can use SBCs. SBCs have potential advantages, such as easier engineering design effort and smaller board space.

However, SBCs have some clear disadvantages. As we’ve stated, the complexity of BCMs vary; therefore, the complexity of power-management and networking functions also vary.

By using an SBC in the BCM, you could be using an SBC device that has extra features that the BCM doesn’t need, making the design potentially more expensive. Instead, if you separate the power-management and networking functions, you can realize the features needed in a specific BCM variant by populating or de-populating relevant devices on the PCB.

Another disadvantage could be the inability to adopt new power-management devices that incorporate innovative technologies to reduce quiescent current, EMI, thermal management, efficiency and size. Using newer, innovative power-management devices in BCMs could reduce engineering effort, make the board space smaller and alleviate EMI challenges.

Since networking devices need OEM approval, incorporating innovative power-management technologies into SBCs could take longer, thus preventing design engineers from taking advantage of innovative power-management techniques.

Finally, SBCs constrain the design of BCMs instead of enabling optimal BCM architectures and even overall vehicle body electronics architectures. The discrete implementation of power-management and networking functions enable the optimization of the overall cost of BCMs due to the flexibility of such implementations.
The power architecture in hybrid and electric vehicles

With the growth in hybrid and electric vehicles, the voltage range, voltage transients and loads connected to the 12-V bus are changing. For example, Figure 9 shows a starter and alternator in a traditional internal-combustion-based vehicle’s 12-V board net, with the BCM connected to the 12-V bus.

In contrast, Figure 10 shows a 48-V bus system in a hybrid electric vehicle, in which the motor/generator connects to the 48-V bus. In this architecture, the BCM is still connected to the 12-V bus.

In 48-V hybrid architectures, the control modules (including BCMs) connected to the 12-V bus are subject to lower maximum input voltages because the alternator is not on the 12-V bus. Lower-input voltages imply that you can use lower maximum-input-voltage power-management devices, which will result in lowering the cost of the BCM.

In this scenario, it would be advantageous to implement power and networking using discrete components because you then have the flexibility to use the BCM with minimal changes in either traditional engine-based vehicles or hybrid electric vehicles.
Conclusion

Automotive BCMs support various functions and features. These differing BCM designs result in the need for different power-management architectures to power all of the ICs on the BCM PCB.

The power-management architectures include:
- The LDO power architecture.
- The first-stage buck architectures.
- The buck-boost architecture.
- Sepic power architecture.
- The first-stage boost architecture.

Which specific power architecture you use depends on the operating voltage requirements, including operating through engine cold-crank and start/stop conditions, the number of voltage rails needed, and the current needed in each rail.

The design of power-management circuits needs to account for many aspects, including the complexity of the power tree, EMI, thermals, board space and cost. You can take advantage of new power-management devices that incorporate innovative technologies to alleviate design challenges in the design of power-management circuits. Moreover, with the advent of higher vehicle bus voltages, you’ll need to optimize BCM designs in order to work under the bus-voltage operating conditions.

For more information, see ti.com/bcm

An overview of the considerations in choosing a power-management architecture

Determining the correct power management depends on several different design challenges. This table lists factors that should be considered when selecting a power-management architecture.

<table>
<thead>
<tr>
<th>Design challenge</th>
<th>Considerations</th>
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| Battery conditions | • Operational through cold-crank?  
                      • Operational through start/stop?  
                      • Is the voltage source not a battery but from a clean source? |
| Number of power rails | • Does the BCM have components that can all be powered by a single voltage?  
                        • Does the BCM have components that have different operating voltage requirements? |
| Load current      | • Is the load current on each output voltage rail small (typically <400 mA)? |
| Size              | • Where will the BCM be located?  
                      • Is the BCM PCB size a top priority due to BCM location? |
| Thermals          | • Where will the BCM be located?  
                      • What is the max ambient temperature at that location? |
| Efficiency        | • How much total power does the BCM require to operate?  
                      • What is the vehicle budget for quiescent (sleep) mode current when the vehicle is not operating |
| EMC               | • Will the power architecture require more design/test time to reach EMC goals? |
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