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# INDUCTORLESS BUCK-BOOST POWER SUPPLY FOR LOW-POWER AUTOMOTIVE SENSOR APPLICATIONS

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## INTRODUCTION

The rapid growth in automotive electronics over the past two decades, coupled with advances in microcontroller and sensor technologies, has increased the demand for high-performance low dropout regulators (LDOs).

Sensor supply voltage regulators have unique requirements such as wide range of input voltage operation with buck-boost mode, low $I_Q$ current, tolerance to output short to battery, small footprint and PCB size, good accuracy, and easy for EMI considerations. These regulators must be automotive-qualified with high operating junction temperature range.

This article discusses the features and applications of Allegro MicroSystems' A4480 regulator IC in automotive low-power systems specifically for sensor supply, and how the IC helps designers meet their challenging requirements.

Power requirements in battery-powered automotive electronics can range from a few hundreds of milliwatts to greater than 100 watts. The simplified automotive DC power system consists of a battery, charging through a generator, supplying power to electronic control units (ECU). An ECU is an embedded system that controls one or more electrical systems or subsystems. Modern vehicles can feature up to 100 ECUs in automotive systems such as engine, transmission, chassis, infotainment, lighting, driver assistance, and other body controllers. One such example of automotive system is electronic power steering. A typical electronic power steering (EPS) application is shown in Figure 1.

The typical automotive ECU consists of a power supply, a microcontroller, sensing and actuation modules, and a data transmitting and receiving module. The electronic systems inside the ECU require DC voltage levels less than the nominal battery voltage of 12 V. During normal operating conditions, the standard 12 V automotive battery voltage can vary from 9 to 16 V depending on load and charge conditions. In a harsh automotive environment, the battery can exerience voltage transients, where input voltage can drop to as low as 4 V during cold crank and can rise to 36 V or even higher during load-dump conditions. For this reason, a DC power supply with appropriate topology is essential to output regulated voltage with such a wide varying input battery voltage.

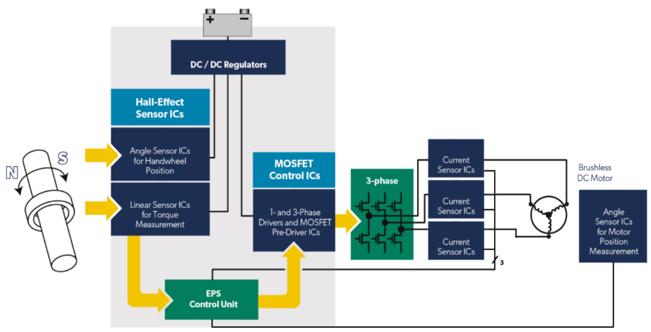


*Figure 1: Typical applications of sensors in EPS applications*

## CHOOSING THE RIGHT LDO FOR AUTOMOTIVE SENSOR APPLICATIONS

A variety of sensors are used in a wide range of automotive applications for measuring angle, displacement, torque, current, pressure, liquid levels, temperature, etc. These sensors are interfaced with a local ECU through a wire harness.

Each of these sensors require a 5 V supply and provide ratiometric analog output voltage proportional to the supply voltage. This needs an accurate LDO output voltage as it impacts sensor measurement. The required 5 V supply can be supplied either by an ECU, or the sensor modules can have a POL regulator to supply the regulated 5 V.

Due to their long wire harnesses, LDOs require satisfactory EMI capabilities. They also require protection against input and output overvoltage, as well as short circuits. Some sensors use the same 5 V supply for both programming and communication using Manchester line communication code. For example, Allegro's A1330 angle sensor and A1367 current sensor both use their supply pin for the programming process. During programming, the LDO may be exposed to high voltage pulses. The LDO should prevent these high-voltage pulses from arcing to other sensitive devices, such as the MCU. The 5 V supply should be able to turn on or off during SLEEP mode to save battery power. ENABLE mode also helps during programming of sensors.

The LDO should operate up to 4 V or below for cold crank applications. The LDO should also have fast transient response, low power dissipation, small PCB size, wide operating temperature range, and—most importantly—must be a lower cost solution.

Sensors normally need currents less than 50 mA. LDOs are advantageous for these applications due to their low power requirement.

Widely, DC power conversion can be achieved through LDOs or switching regulators. An LDO is a linear regulator which can operate with a very small voltage difference between the output voltage and the input voltage. Since LDOs are linearly regulated, they have fast dynamic response, low output noise and high-power supply rejection ratio. Additional advantages of LDOs include low quiescent current, ease-of-use and simplicity, low solution cost, and small size – LDOs require only two off-chip capacitors. The low quiescent current and low dropout features of LDOs make them appropriate for use in automotive applications where low quiescent current is critical to limit battery drain during standby conditions and low dropout is necessary during cold-crank conditions.

Nevertheless, LDOs are inherently inefficient if the voltage headroom, or the difference between input and output voltage, is large or load current is high, i.e., high output power. Under these conditions, LDOs may require an external heat sink which increases the cost, complexity, and size. A non-conducive automotive environment, high ambient temperature, and little or no airflow further limits the usage of LDOs only in low power applications. Another major limitation is that LDOs can only step down the input voltage, so depending on LDO output voltage requirement, a complex buck-boost pre-regulator may be required, particularly with wide varying automotive input voltage, to always maintain LDO input voltage higher than its output.

Switching regulators can provide better efficiency and operational range but higher system cost prohibits their applications as sensor bias supply.

Capacitor-based switching regulators, also called charge pumps, are often the best choice for powering an application that requires the combination of low power, wide operating range, and low solution cost. Charge pumps are simpler and require just a few small and inexpensive ceramic capacitors.

Charge pumps can easily achieve higher efficiency than LDOs. Charge pumps attain maximum efficiency when operated at an intrinsic conversion ratio which is unique to the charge pump topology. Any attempt to change the operating conversion ratio from the intrinsic conversion ratio, for the purpose of output regulation, increases the charge transfer losses and reduces the efficiency of charge pump. Output of a charge pump pre-regulator can be regulated by cascading an LDO at the output of charge pump. Although slightly inefficient, cascading is widely adopted in sensitive applications which demand ripple and noise-free input voltage rails.

## INDUCTORLESS BUCK-BOOST POWER IC

Allegro MicroSystems' A4480 is a unique inductorless buck-boost LDO suitable for low-power automotive applications, such as sensor bias supply.

The A4480 is a fixed 5 V, 50 mA regulator with wide input operating voltage of 3.5 to 28 V with 40 V load-dump capability. Figure 2 shows the functional block diagram. The internal power path of the A4480 comprises a charge pump-based pre-regulator followed by an LDO. The charge pump pre-regulator operates as a buck-boost converter and converts the wide varying automotive input voltage of 3.5 to 28 V into a loosely regulated intermediate voltage $V_{REG}$, which is always greater than 5 V. The output LDO converts $V_{REG}$ voltage into a precisely regulated, fixed 5 V output. The charge pump is operated at a low switching frequency of 325 kHz, well below the AM frequency band of 530–1800 kHz, to easily comply with CISPR 25 automotive EMC standards. Based on the input voltage, the charge pump pre-regulator can operate in any one of the three modes: boost, pass-through and buck.

The IC provides low quiescent current sleep mode when ENB is pulled low. This allows an LDO to be used directly from the battery.

The A4480 draws an extremely low input sleep current of 1 µA-typical when disabled. The low input sleep current limits the battery drain when automotive engine is off and also helps to meet most of the automotive OEM's sleep current specification (e.g.,~100 µA/ECU). The A4480 also incorporates a high voltage, 40 V rated enable pin (ENB) which allows it to be directly connected to battery for automatic enable at key switch turn-on.

The A4480 is automotive AEC-Q100 qualified and integrates robust protection and diagnostic features to satisfy highly demanding and safety-critical automotive applications. Protection features of the A4480 include input undervoltage lockout, output under/overvoltage, foldback current limit and thermal shutdown. The foldback current limit protects the A4480 during output short-to-ground fault. In addition, the A4480 provides output short-to-battery protection, which is critical in automotive applications where power supplies are connected to loads via long wiring harness. The A4480 includes an open-drain diagnostic output Power OK ($P_{OK}$) to alert the system microprocessor when a fault has occurred. Also, the A4480's pinout is FMEA compliant for pin-to-pin short and pin-to-ground short.

The 5 V ±2% precision regulated output across wide input voltage, output current, and automotive-focused temperature range ($T_J$ of –400°C to 1500°C) makes the A4480 suitable for powering low-power automotive sensors.

**Boost Mode:** When input voltage is less than 7.8 V during $V_{IN}$ rising or less than 6.9 V during $V_{IN}$ falling, the charge pump enters into boost mode and operates as a doubler thus providing nearly twice the input voltage at $V_{REG}$. This mode allows stable 5 V output regulation even when $V_{IN}$ drops to a threshold that would otherwise cause a standard LDO to lose regulation.

**Pass-through Mode:** When input voltage is greater than 7.8 V and less than 11.5 V during $V_{IN}$ rising or less than 10.5 V and greater than 6.9 V during $V_{IN}$ falling, the charge pump enters into pass-through mode and only outputs the input voltage at $V_{REG}$. In this mode, operation of charge pump is similar to that of a standard LDO.

**Buck Mode:** When input voltage is greater than 11.5 V during $V_{IN}$ rising or greater than 10.5 V during $V_{IN}$ falling, the charge pump enters into buck mode and operates as a ½ divider, providing nearly half the input voltage at $V_{REG}$. This mode offers significant power loss reduction when compared to a standard LDO.

*Three functional modes in the charge pump enable operation as a buck, boost, or "pass-through" LDO without using an inductor*

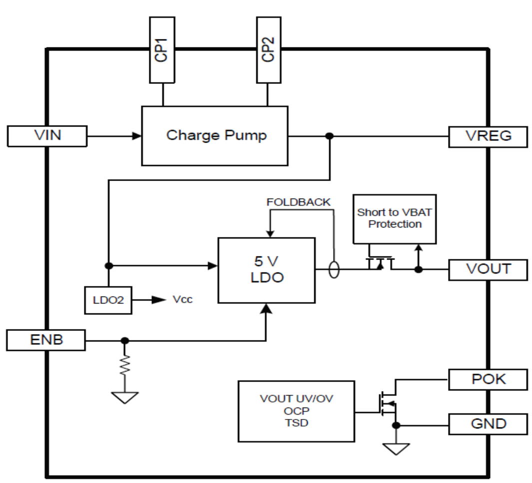


*Figure 2: Functional block diagram of the A4480*

## Device Performance:

Figure 3 shows the steady-state efficiency of the A4480 with rising and falling input voltage, compared to a standalone 5V output LDO. From figure 3, it is evident that when in buck mode, efficiency of the A4480 is significantly higher than that of an LDO, and while in pass-through mode, efficiency of the A4480 is equal to that of an LDO.

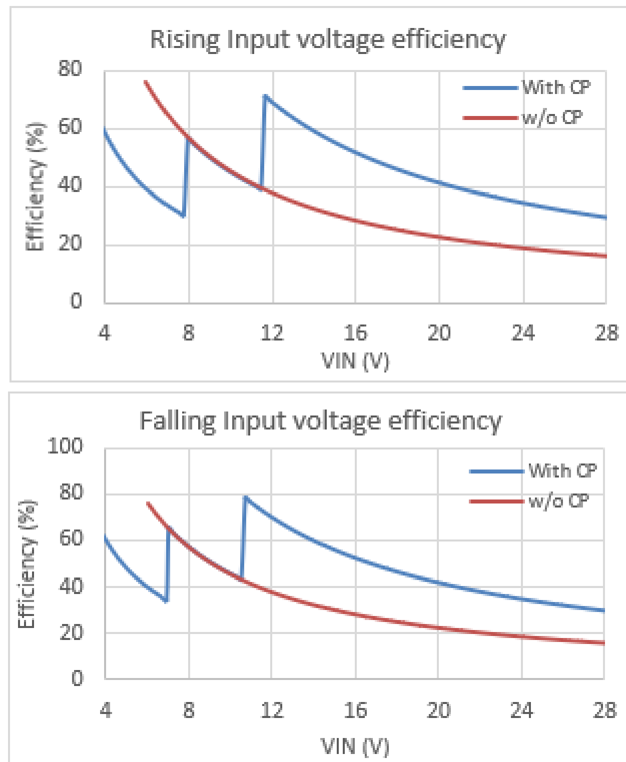


*Figure 3: Comparison of steady state efficiencies of the A4480 and an LDO*

Figure 4 shows the steady-state power loss of the A4480 compared with that of a standalone 5 V output LDO. Power loss in the A4480 is significantly lower at the typical operating input voltage of 12 V. This allows the A4480 to run cooler and enables the use of smaller PCBs.

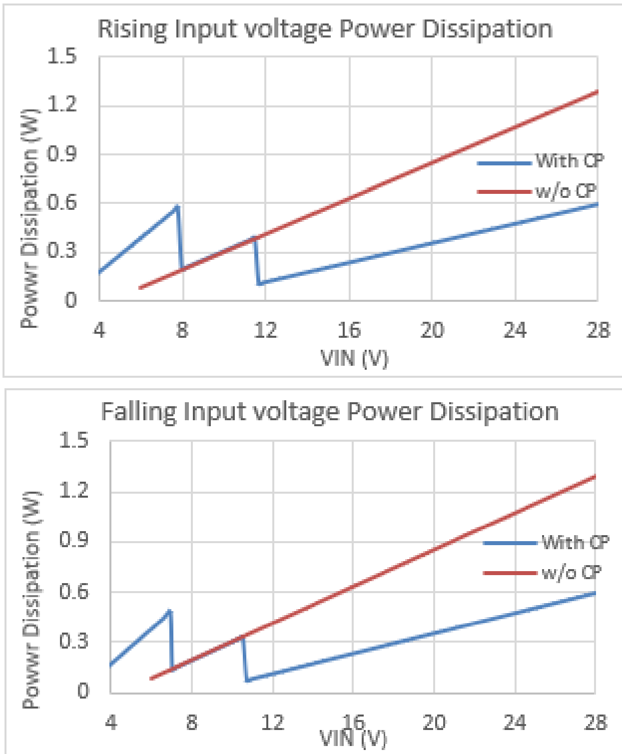


*Figure 4: Comparison of steady state power dissipation of the A4480 and a standalone LDO*

Figure 5 shows the LDO and board temperature on a 2-layer, 25 mm × 35 mm size, 1 oz double-sided PCB operating with a nominal supply voltage of 12 V. Testing is done at an ambient temperature of 31°C with no airflow. Note that the A4480 experiences a temperature increase of 7°C, compared to 19°C seen in a conventional LDO.

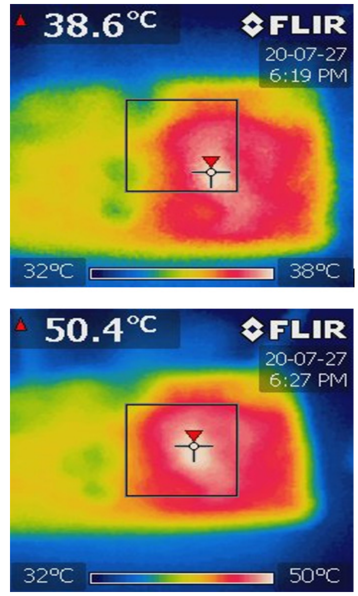


*Figure 5: Comparison of steady state temperature increase of the A4480 and a standalone LDO at 12 V, 50 mA current on a 25 mm × 35 mm PCB.*

Figure 6 shows the transient operating waveforms of the A4480 during input voltage variation from 12 V to 4 V, back to 12 V while delivering 50 mA output current. With 12 V input, the charge pump operates in buck mode and produces $V_{REG}$ voltage less than the input. With 4 V input, charge pump operates in boost mode and produces $V_{REG}$ voltage greater than the input. The output LDO ensures strictly regulated 5 V output from the A4480.

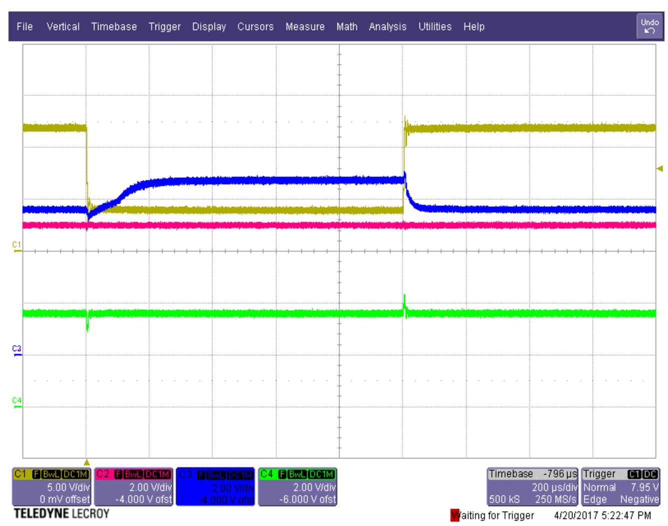


*Figure 6: Input voltage Transient waveforms*
*C1: VIN, C2: VOUT, C3: VREG, C4: POK*

Figure 7 shows the operating waveforms of the A4480 during load-dump transient compliant with ISO 16750 pulse 5b.

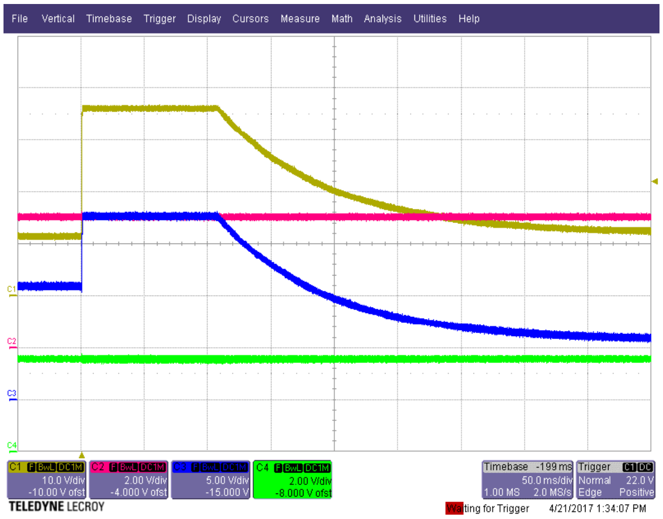


*Figure 7: Transient waveforms during load-dump*
*C1: VIN, C2: VOUT, C3: VREG, C4: POK*

## CONCLUSION:

The inductorless buck-boost operation of the A4480 offers several advantages:

1. Stable 5 V operation even when $V_{IN} < V_{OUT}$ (e.g., low $V_{IN}$ LDO replacement)
2. Simple design, lower cost due to fewer external components – four ceramic capacitors.
3. Small PCB size due to reduced component count and lower power dissipation.
4. Less layout sensitivity and low EMI.
5. Rugged and fault tolerant.

The above advantages make the A4480 an ideal solution for low-power automotive applications such as sensor, microcontroller, and transceiver power supplies.

<table>
<tr><th>Characteristic</th><th>A4480</th><th>Conventional LDO</th><th>Advantage for sensor interface</th></tr>
<tr><td>Operation below 5 V input</td><td>Good</td><td>N/A</td><td>Allows low voltage operation</td></tr>
<tr><td>Power loss at 12 V input</td><td>0.11 W</td><td>0.41 W</td><td rowspan="4">Less power dissipation due to:<br>• Smaller PCB<br>• Extended operating temperature and Vin range<br>• Higher output current</td></tr>
<tr><td>Temperature Rise at 12 V input</td><td>–</td><td>–</td></tr>
<tr><td>Power loss at 25 V input</td><td>0.47 W</td><td>1.07 W</td></tr>
<tr><td>Temperature rise at 24 V Input</td><td>–</td><td>–</td></tr>
<tr><td>Output voltage max rating</td><td>28 V</td><td>Typ. 5.5 V</td><td>• Allows short to battery and protect loads connected to the DC bus.<br>• Allows programming of sensors requiring higher voltage</td></tr>
<tr><td>Accuracy</td><td>±1%</td><td>Typ. ±2%</td><td>Better for accurate sensor output measurement</td></tr>
<tr><td>Transient Response</td><td>Good</td><td>Fair</td><td>–</td></tr>
<tr><td>Low $I_Q$ and EN</td><td>Good</td><td>Fair</td><td>Allows direct battery operation</td></tr>
</table>

*Revision History*

| Number | Date | Description | Responsibility |
|---|---|---|---|
| – | September 10, 2021 | Initial release | Shashank Wekhande |

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