



Innovations Embedded

CMOS LDO Regulators

for portable devices



CMOS LDO Regulators for Portable Devices

Introduction

Power management has become an increasingly important design consideration for numerous products, especially those relying on battery power. Complicating the power management situation, as more features get integrated into products, the number of required voltage supplies increases. With a common 3.6-V lithium-ion battery, a highly integrated product such as a smart phone can require ten or more different voltages for:

1. *Global positioning system (GPS)*
2. *Power amplifier*
3. *Memory*
4. *Baseband and DSP core*
5. *Applications (picture, music and video) processing*
6. *Low voltage wireless LAN*
7. *Display back light LED drivers*
8. *Display CCD*
9. *Audio*
10. *Photo flash charger*

To handle all of these voltages, cell phones typically have power management ICs with multiple LDOs. However, depending on the location of the load, an individual LDO may be used.

While switching regulators garner a lot of attention because of their high efficiency, low drop-out (LDO) linear voltage regulators offer the optimum answer for powering circuitry in many of the portable device applications. The latest generation of LDOs is optimized for cell phones, PDAs, MP3 players, notebooks, cameras, camcorders and other handheld portable systems.

LDOs provide a power management solution satisfying the need for low power, space-conscious design and low switching-noise voltage regulation while adhering to the cost constraints of these applications.

Other LDO applications include PC motherboards, graphic cards, post-regulation in switching power supplies, telecom equipment and consumer applications such as HDTVs. In addition, automotive applications continue to use LDOs for their low switching noise and low cost.

According to Susie Inouye, Research Director and Principal Analyst at market research firm Databeans, "LDOs are still the best fit for low current applications. They are inexpensive and have lower noise than more complex switching regulators. Noise performance in portable electronics is an important design consideration, particularly in wireless as high frequency parts can impact performance of sensitive analog RF circuits. As long as price, size, and noise performance matter, there will be a growing market for LDOs."

Databeans forecasts a compound average growth rate (CAGR) of 15% unit growth for LDOs from 2009 to 2014. Advances in the latest CMOS LDOs are among the reasons for this growth.

This paper reviews the basics of LDO regulators and discusses the technology advances in the latest generation of LDOs that make them the preferred solution for many point of load power requirements. The paper will also introduce ROHM Semiconductor's extensive line of CMOS LDO regulators and discuss their unique benefits in portable electronics applications.

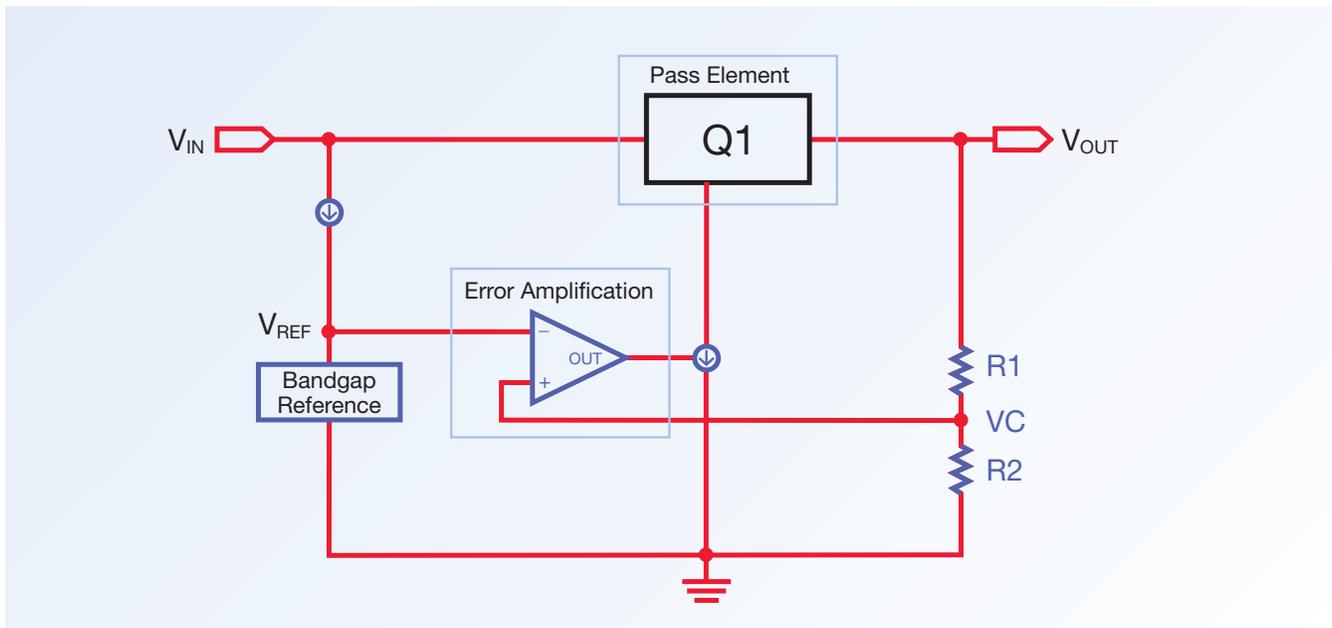


Figure 1. The pass element, Q1, in a low drop out regulator operates in the linear range and can be a bipolar NPN or PNP transistor, a Darlington pair, or an N-channel or P-channel MOSFET.

The Basic LDO Topology

Low drop-out linear regulators are designed to operate with minimal voltage differences between the source voltage (V_{IN}) and the regulated output voltage (V_{OUT}). This value, known as the saturation voltage (V_{SAT}) is typically in the 100 mV to 200 mV range. This allows for effective regulation of load voltages as battery voltage diminishes as the battery discharges.

The basic LDO topology is shown in Figure 1. Using a resistor divider, a voltage-controlled current source determines the output voltage. Key elements include the voltage reference, an error amplifier and the series pass transistor. Input and output capacitors are typically among the few external components required for proper LDO operation.

Advanced LDOs utilize BiCMOS process technology to provide higher efficiency, additional application-specific features and space-saving packaging. With BiCMOS, a merged bipolar and CMOS wafer fabrication process, an LDO designer can take advantage of circuit elements of each technology. For example, the bandgap reference is an ideal bipolar circuit element while the output pass transistor can be a highly efficient P-channel MOSFET that results in very low

operating current. (For example, ROHM's recently introduced [PB1](#) series requires just 20 μA under high-speed operation and only 2 μA when in its unique power-save mode.) The resulting LDO design provides optimized performance for portable applications.

Comparison of LDOs to PWM Regulators

For the majority of applications within portable devices where loads are operated from a battery source, the LDO offers a simple, small and cost-effective solution. While it is true that switching regulators are more efficient than LDOs, there are several other factors that must be considered in selecting the right device for the job.

Pulse-width modulated (PWM) switching regulators typically operate between 50 kHz to 1 MHz and produce electromagnetic interference (EMI) that can disrupt both analog and RF circuits. In contrast, the switching in LDOs occurs in the bandgap reference and the level is in the microvolt, rms range over a defined bandwidth, a level that is considerably lower than a switching regulator. This is a major design advantage in noise-sensitive applications.

Additional advantages of fewer external components, simple design process, small footprint, and lower cost make LDOs a preferred solution for regulated power in many applications where the controlled voltage is lower than the source voltage. Moreover, the latest advances in CMOS LDOs, such as BiCMOS devices with a P-channel output transistor and power down capabilities as found in ROHM CMOS LDO regulators, significantly reduce the efficiency advantage of PWM regulators – particularly in low-current applications.

Table 1 summarizes the significant points of comparison between LDO and switching regulators.

Selecting the Right LDO for the Job

An LDO's drop out voltage, the type and range of input voltage, required output voltage, maximum load current and power dissipation (P_d) are key factors in product selection. In portable applications, it is also important

Regulator Type	Linear (LDO)	Switching
External Components	advantage	---
Noise sensitivity	advantage	---
Design Complexity	simple	complex
Cost	advantage	---
Footprint	advantage	---
Step-down (buck voltage)	yes	yes
Step-up (boost voltage)	no	yes
Efficiency	---	advantage
Thermal design	---	advantage

Table 1. Compared to switching regulators, LDOs have several design areas where their advantages make them a compelling choice.

to consider the level of electrostatic discharge (ESD) withstand capability. Finally, package size must be taken into consideration in selecting the right device for space-conscious portable devices.

Figure 2 illustrates several features that can be added to an LDO to satisfy application requirements in the latest portable and wireless products. This paper will discuss the importance of many of these features.

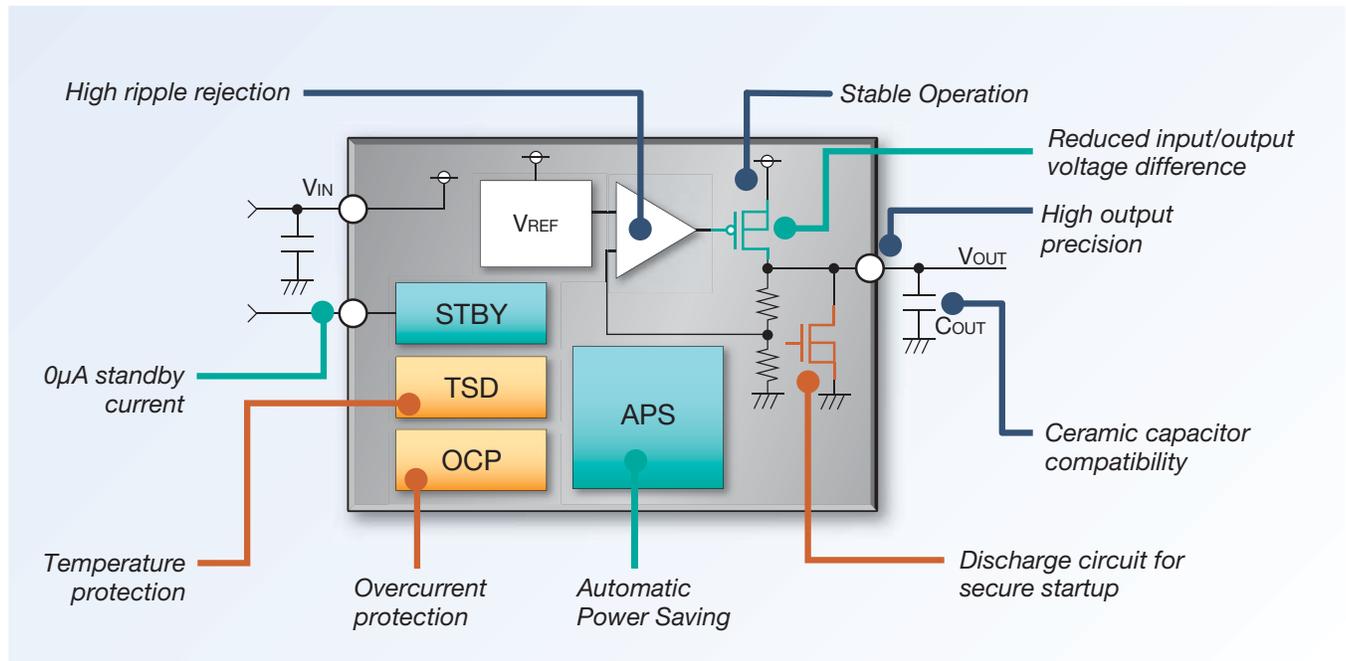


Figure 2. Additional circuitry and advanced packaging can make an LDO the ideal choice for a particular application. ROHM CMOS LDO regulators are available in several series offering many of these advanced features.

■ Package Size and Power Dissipation

Packaging has a significant impact on PCB space and power dissipation. For example, an HVSO5 (1.6 x 1.6 mm²) packaged LDO is over 70% smaller than a 2.8 x 2.9-mm² SOT23-5, achieving the same current rating while improving the effective power dissipation (P_d).

■ Automatic Power Saving Function

With CMOS processing, advanced features such as an Automatic Power Saving (APS) function can be designed to further increase the efficiency of an LDO. With APS, the circuit varies the current consumption based on the value of the load. This can result in as much as 90% less current during no load conditions.

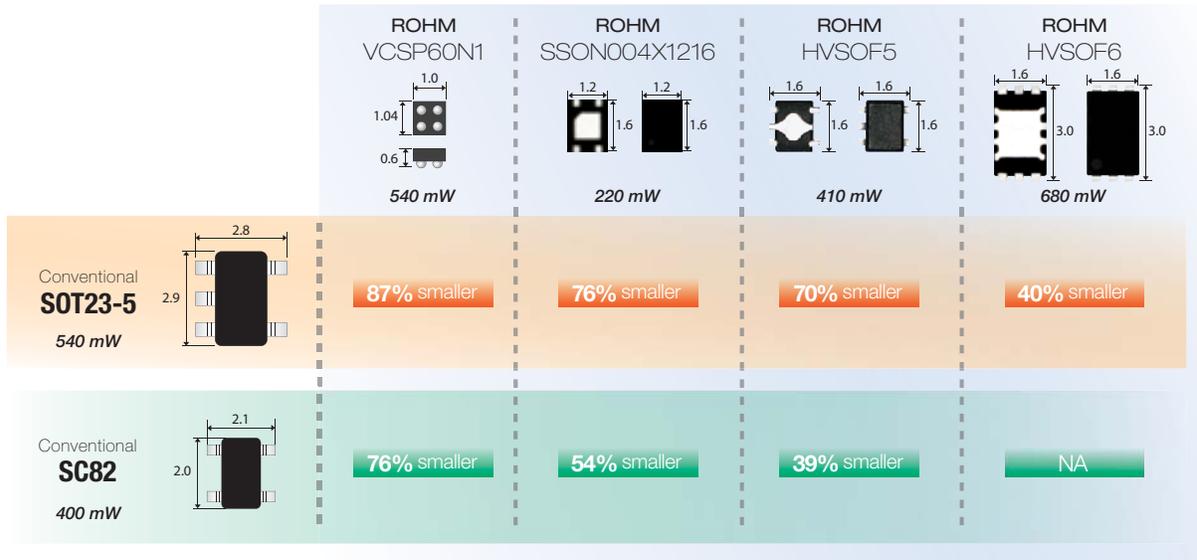


Figure 3. A small LDO package provides a substantial space savings for portable applications and with the right substrate design, can dissipate 100s of milliwatts.

Figure 3 shows the size reduction of four ROHM LDO packages and nominal power dissipation compared to the industry-standard SOT23-5 (ROHM SSOP5) and SC82 packages.

In many packages, an integrated heatsink increases the heat transfer allowing the package to safely dissipate more heat. The ability to dissipate more heat is especially useful in high-density portable devices. The safe power dissipation for a particular package also depends on the ambient temperature and mounting substrate. Package ratings (e.g. SSOP5: 540 mW; HVSO6: 680 mW; HVSO5: 410 mW; SSON004X1216: 220 mW; and VCSP60N1: 540 mW; VSON008X2030: 660 mW) are for power dissipation at 25°C operation. The value of P_d normally decreases with increasing ambient temperature. In addition, the power dissipation will differ depending on the mounting conditions and substrate (board type, size and copper foil area).

■ High-Speed Load Response

CMOS LDOs are ideal for powering microcontrollers, digital signal processors, microprocessors, memory and other digital logic circuits. A critical feature in this application is high-speed load response. If the regulator does not respond quickly enough, its output has the potential to fall below the minimum voltage differential required for reliable operation. A low V_{SAT} allows stable operation even when the battery is close to being fully discharged.

Figure 4 demonstrates the importance of fast load response. A “conventional” LDO exhibits nearly 100 mV drop in V_{OUT} , compared to the ROHM BUxxJA2 Series LDO optimized for high-speed load response. This added margin can reduce the potential for “drop-out” and extend operation as the battery voltage approaches discharge.

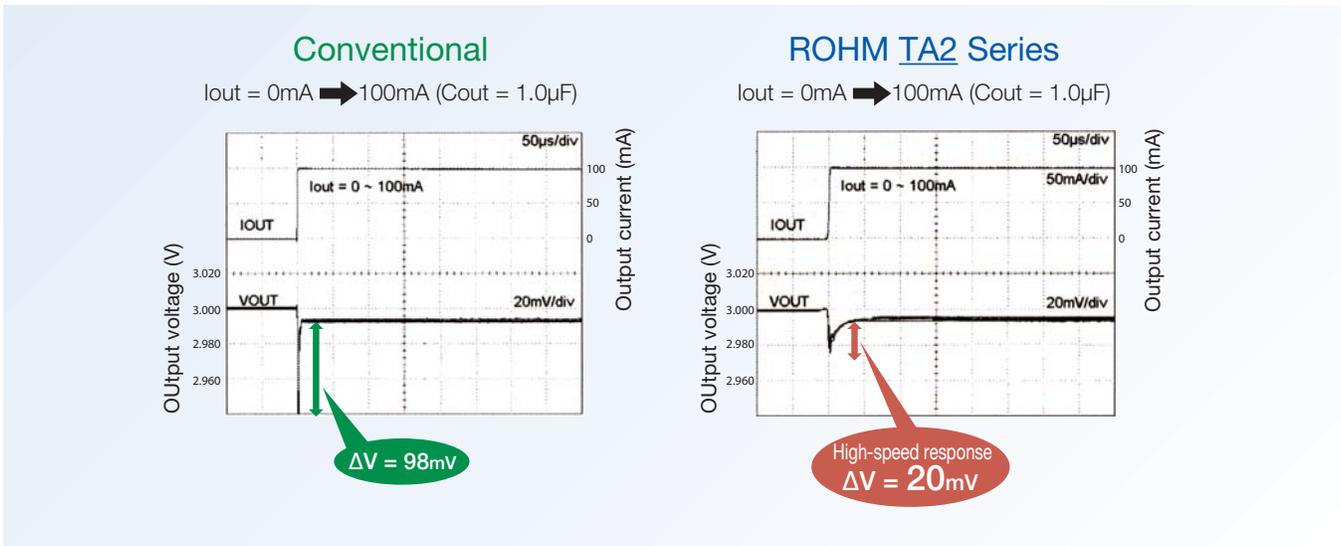


Figure 4. A high-speed load response LDO assures that the output voltage regulation can be sustained, even as the battery voltage falls as the battery is close to being fully discharged.

■ Ripple Rejection and Circuit Footprint

LDOs are also used to power RF and analog circuitry in portable consumer products. LDOs optimized for high ripple rejection insure a clean output for powering these circuits. (See Figure 5.) Devices equipped with internal phase compensation provide higher levels of ripple rejection, often without the need for external filter capacitors, resulting in a simpler solution and smaller circuit footprint.

■ Reverse Current Protection and Circuit Footprint

If V_{IN} is lower than V_{OUT} when the LDO is turned off, (due to a residual charge on the output capacitor, for example) a damaging reverse current could flow from the output to the input. A standard feature of all ROHM CMOS LDOs is an internal circuit, as shown in Figure 6, which safely discharges the output capacitor without the need for external blocking diodes and further reduces the overall circuit footprint.

■ Overtemperature and Overcurrent Protection and Thermal Design

Built-in foldback type overcurrent protection prevents damage and can reduce the heating effects of current overload conditions on the LDO and surrounding circuitry. Thermal protection further restricts the device's temperature. These protection circuits combine to limit total heating during operation and can simplify thermal design.

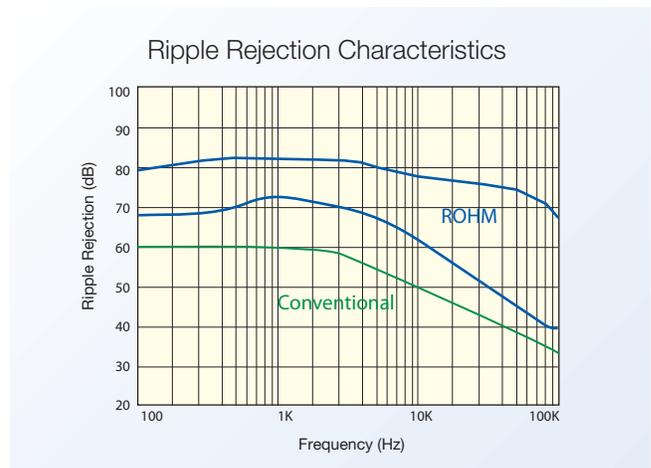


Figure 5. Internal phase compensation significantly enhances ripple rejection without the need for external filter capacitors. Some ROHM LDOs attain rejection ratios of 70 dB and higher as shown by blue traces as compared to typical devices.

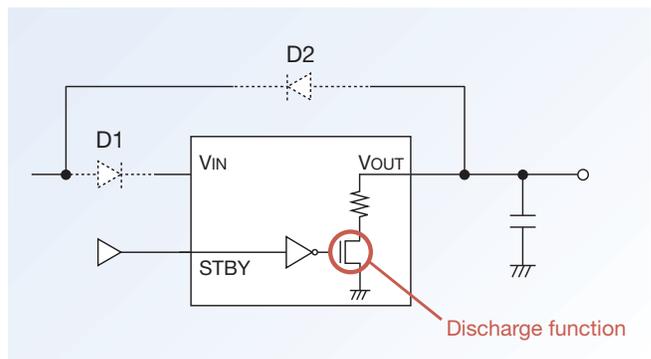


Figure 6. An internal discharge circuit prevents reverse current flow and eliminates the need for diodes D1 and D2.

ROHM Semiconductor LDO Solutions

ROHM Semiconductor CMOS LDOs for portable devices provide designers several advantages including:

- High-accuracy output voltage $\pm 1\%$ over a wide temperature range
- Compatible with compact ceramic capacitors for an overall smaller footprint
- Low current consumption (as low as $20\ \mu\text{A}$ with the *BHxxPB1* series in high-speed mode)
- $0\ \mu\text{A}$ standby current
- Built-in foldback type overcurrent protection (See Figure 7)
- Built-in thermal shutdown
- Built-in discharge circuit to prevent malfunction when entering standby mode or at power-on
- High ESD protection
- Soft-start [*BH6733*]
- Automatic Power Saving (APS) function to reduce power consumption during light-load conditions [*BHxxPB1* series]
- High ($300\ \text{mA}$) output current [*BHxxMA3* series]
- High ripple rejection of $70\ \text{dB}$ or even $80\ \text{dB}$ [*BHxxNB1* series]
- High-speed load response
- Ultra-compact molded package [*BHxxTA2* series] or chip scale package [*BHxxRB1* series]

These performance advantages are implemented in a variety of product families (indicated above in brackets).

Standard CMOS LDOs [*LB1* and *FB1* series] from ROHM Semiconductor have a low ($40\ \mu\text{A}$) current consumption and high ($70\ \text{dB}$) ripple rejection in a small ($1.6 \times 1.6\ \text{mm}^2$) HVSO5 package. (Also offered in the industry-standard SOT25-5 package.) The low current consumption provides extended battery life in portable applications. High ripple rejection assures a stable output for improved performance. These products provide a good starting point for many portable products, such as camcorders, notebook computers and MP3 players. For tighter design criteria, other families extend these capabilities and add functionality for higher performance.

Automatic Power Saving Function LDOs [*PB1* series] continuously monitor the output current and automatically select either the low current consumption or the high-speed operation circuit depending on real time conditions as shown in Figure 8. This unique approach reduces operating current to just $2\ \mu\text{A}$ under light-load conditions. Another design feature is the output discharge function that reduces the time duration of $0\ \text{V}$ during start up from 1 second to 10 ms for improved stability. Inrush current protection, overcurrent protection, thermal shutdown, $1.7\ \text{V}$ operation, 1% voltage accuracy and $8\ \text{kV}$ ESD protection are among the added features in this product family for increased durability and performance. This family provides an excellent solution for extending the battery life in cell phones and other handheld portable products.

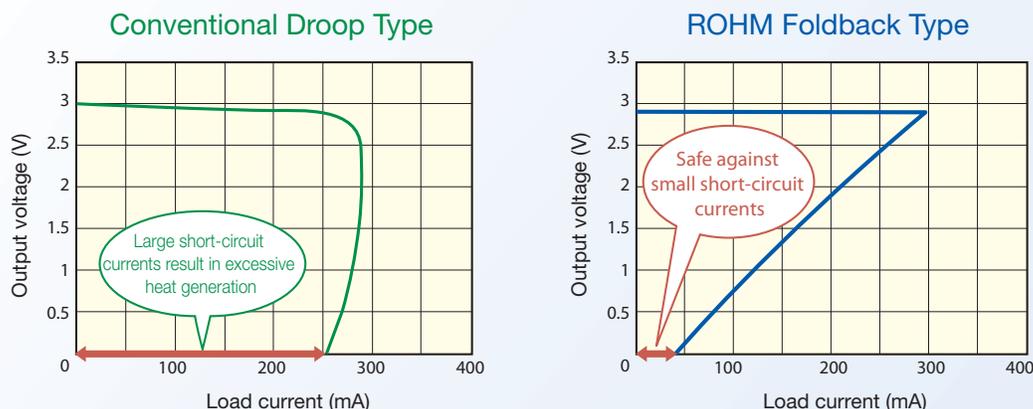


Figure 7. Foldback overcurrent protection reduces device heating during fault conditions.

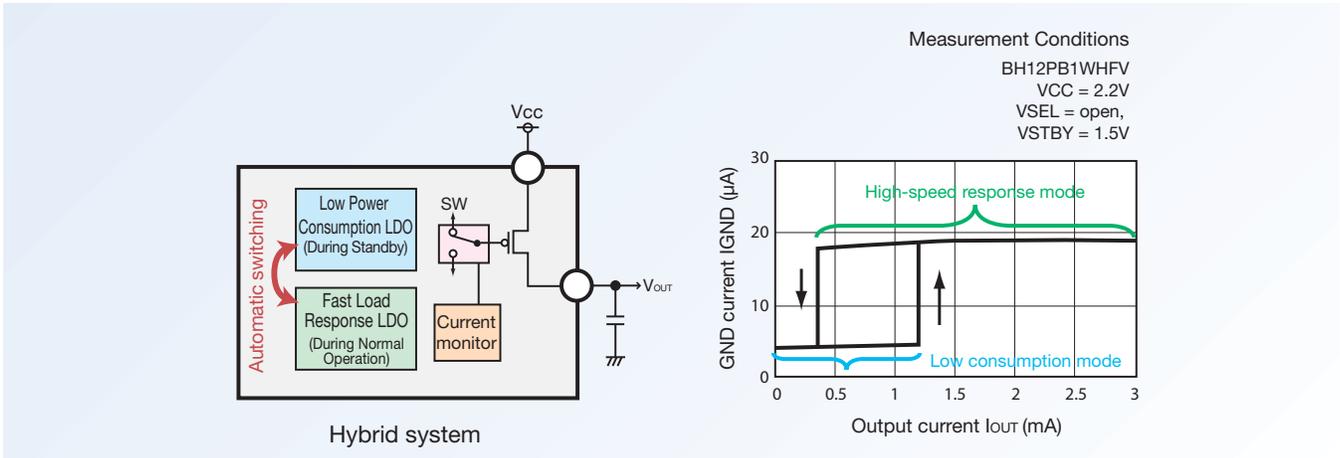


Figure 8. The automatic switching between low power consumption and fast load response modes in ROHM Semiconductor's proprietary Automatic Power Saving (APS) function provides a power savings without compromising performance.

High current [MA3 series] LDOs include a proprietary feedback circuit, low ON-resistance, and two parallel output terminals (see Figure 9) to enable stable load regulation as low as 6 mV compared to conventional regulators at 30 mV. The compact (1.6 x 3.0 mm²) high power (P_d = 680 mW) HVSO6 package has an underside heatsink for high thermal dissipation. In addition to higher power loads in battery-powered products, this higher current LDO can handle loads in graphics cards, telecom equipment and consumer applications such as HDTVs.

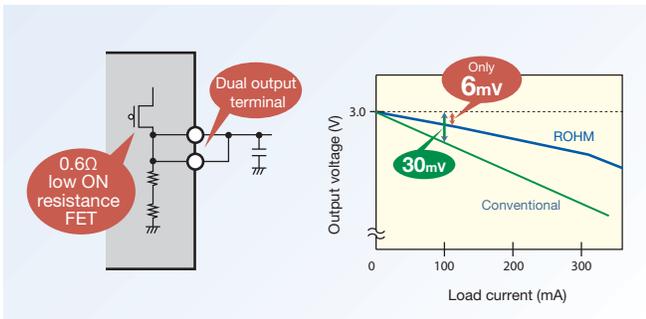


Figure 9. ROHM's MA3 series LDOs exhibit a voltage drop of just 6 mV (I_{out} = 100 mA) instead of 30 mV in comparable devices.

High speed load response [TA2 series] LDOs reduce the fast load response to just 20 mV while transitioning from 0 to 100 mA output current compared to conventional regulator values of up to 98 mV as shown in Figure 10. Offered in the ultra compact

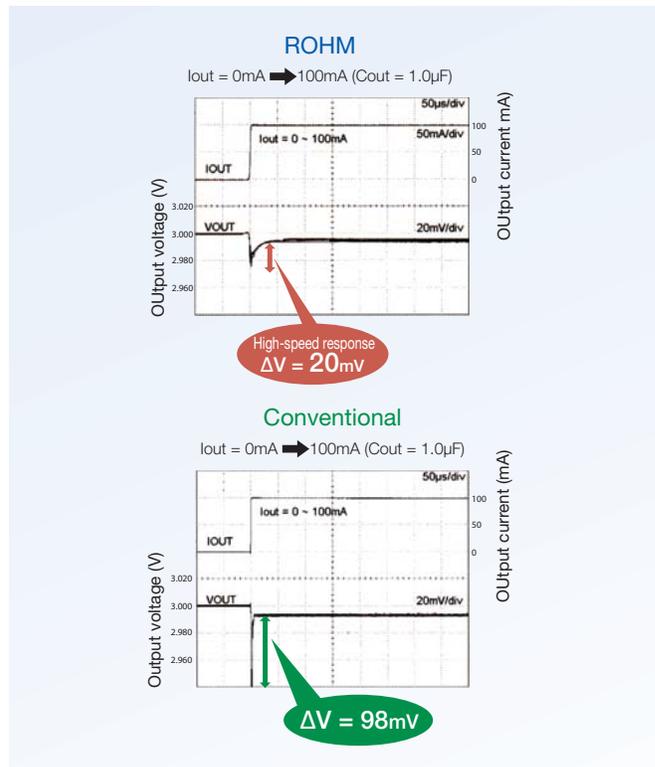


Figure 10. High-speed load regulation reduces load response from nearly 100 mV to only 20 mV with an output step-change from 0 to 100 mA.

SSON004X1216 (1.6 x 1.2 x 0.6 mm³) package, TA2 series devices are 25% smaller than the H5V0F5. Ideal for high-speed processing and data reading in high-density logic and memory applications, these LDOs are frequently used in portable audio circuits and in digital cameras as well as portable computers, PC mother boards and graphic cards.

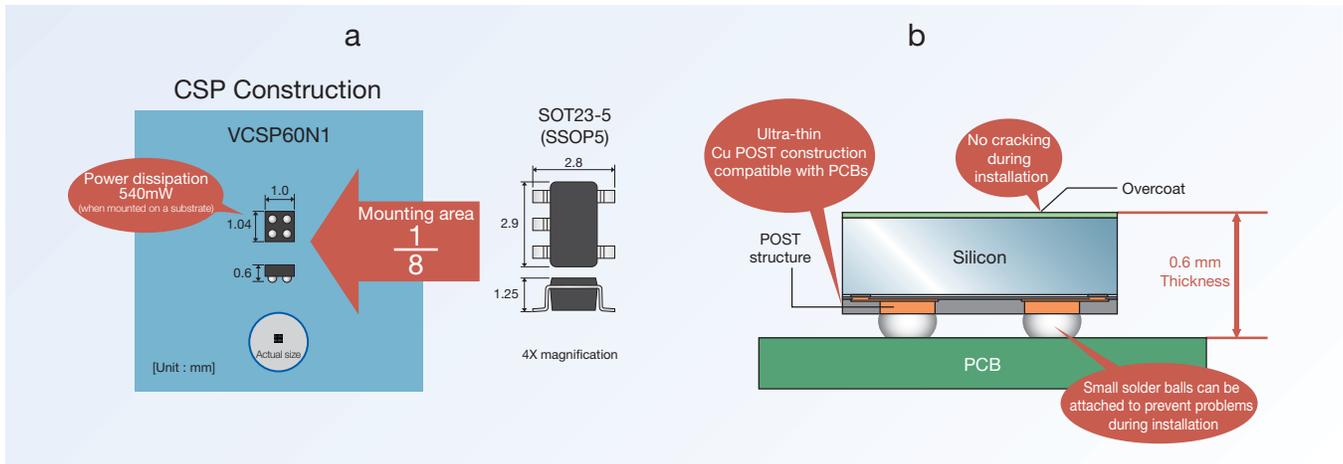


Figure 11. LDO products in the Chip Scale Package (CSP) (a) occupy 1/8 the mounting area of a SOT23-5 package and (b) utilize sophisticated packaging techniques to avoid reliability problems during assembly.

High ripple rejection [NB1 series] provide an additional 10 dB of margin for a total 80 dB at 1 KHz and improved ripple rejection over a broader frequency range. These units also have 6 mV load regulation and 1 mV line regulation ensuring stable power supply operation even in applications with significantly varying load currents. In addition, proprietary phase compensation circuitry in the design may eliminate the need for an external capacitor providing space reduction and lower system cost. This family provides improved line and load regulation for analog applications in portable products such as sensor and audio applications common in cell phones, camcorders and digital cameras.

The Chip Scale Package (CSP) [RB1 series] provides an even smaller footprint than ultra-small molded packages. The 4-pin CSP shown in Figure 11(a) measuring $1.04 \times 1.0 \times 0.6 \text{ mm}^3$, just slightly larger than the chip itself, has a mounting area that occupies only $1/8$ of the PCB space of a standard $2.8 \times 2.9 \times 1.25\text{-mm}^3$ SOT23-5. Increased performance capabilities come from the **RB1 series'** low input/output voltage difference of 100 mV @ $I_o=100 \text{ mA}$, and current consumption as low as 34 μA making it highly desirable in lower input voltage applications. As shown in Figure 11(b), CSP technology includes design considerations that improve reliability and minimize end product manufacturing problems. The **RB1 series** is ideal for portable applica-

tions under the most severe space constraints such as smart cell phones and digital cameras.

The three-channel output, BU665xNUX Series combines a number of the advantages of the single-channel ROHM CMOS LDOs while providing three independent outputs in a single, compact device that reduces mounting costs and board wiring. Three combinations of output voltages are offered, each with 200 mA per channel output current ($P_d = 660\text{W}$, max.), low current consumption and ON/OFF control for each channel as well as 1% output voltage tolerance, over-current protection and thermal shutdown.

Conclusion

As battery powered, wireless products proliferate, system designers can continue to count on LDOs for regulated power sources with low noise and space saving design. Specifically designed for low power applications in portable products, ROHM Semiconductor CMOS LDOs provide a variety of solutions for efficient and cost-effective power management. Package size, power efficiency, dynamic regulation and ripple rejection are among the features that should be considered in making an LDO selection. ROHM Semiconductor's complete line of CMOS LDOs combined with expert application engineering support assures the optimum choice for every application.



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