No Tradeoffs: Linear Power Supplies for Ultra-Low Power and Dynamic Performance

Design engineers are increasingly looking to shrink power management components in modern electronics, while also making them more efficient. In battery-operated applications, the main constraints are: the size of the system, the size of the battery, and the ability to respond to dynamic loads. Designers must now select power supplies that address these constraints. One such device is the TPS7A02.

Extending Runtime of the Application

Quiescent current (I\textsubscript{Q}) is a critical parameter in battery-powered systems. (To learn more about quiescent current, see the LDO Basics eBook). This parameter refers to the current consumption of the device in an enabled, light-load situation. In the case of TPS7A02, this device has an ultra-low I\textsubscript{Q} of 25 nA which is achieved by utilizing multiple techniques to ensure minimal current draw.

A traditional LDO consists of a pass device, a voltage reference, and an error amplifier, as Figure 1 shows. The voltage reference and error amplifier are the major consumers of current and typically contribute > 80% of the overall current consumption of the device.

One way to reduce current consumption is by taking advantage of a dynamic biasing circuit. This circuit enables on-the-fly tradeoffs by automatically controlling auxiliary circuits within the regulator which will boost the ground current (I\textsubscript{Q} at no load) at a certain level of load without compromising light-load efficiency.

This allows the ground current consumed by the regulator to maintain a very high current efficiency as compared to the load current consumed by the system, as shown in the Ground Current Efficiency vs Output Current figure in the TPS7A02 Nanopower I\textsubscript{Q}, 25-nA, 200-mA, Low-Dropout Voltage Regulator With Fast Transient Response Data Sheet. Equation 1 can be used to calculate the current efficiency (I\text{\eta}) of a system.

Another feature that sets the TPS7A02 apart from traditional LDOs is its I\textsubscript{Q} performance during a dropout condition. This is a very helpful feature to have in battery-powered systems as the battery will deplete over time and approach the output voltage. Typical LDOs show a behavior similar to Figure 2, where I\textsubscript{Q} has an overshoot when the device enters into dropout. Thus this may have a negative impact on a product by shortening its battery life.

As Figure 3 shows, when the TPS7A02 experiences a dropout condition, the device uses the improved dynamic-biasing circuit mentioned previously to change the error amplifier loop to allow for proper regulation while maintaining I\textsubscript{Q} performance. A device that can inherently do this can increase the lifetime of a battery-powered application.

\begin{equation}
I_{\eta} (\%) = \frac{I_{\text{OUT}}}{I_{\text{OUT}} + I_{Q}} \times 100
\end{equation}
Maintaining Dynamic Performance

Dynamic performance is the most important design tradeoff when considering devices used to minimize the power consumption of a system. It can be distilled into the performance of either the load or line transients. Having the output voltage respond quickly to changes in load or line voltage with minimal deviation is critical when powering sensitive analog and digital loads.

Low $I_Q$ devices have traditionally had slower dynamic performance. A device like the TPS782, for example, boasts 500-nA $I_Q$ and a load transient response as shown in the Load Transient Response. TPS78233 figure in the TPS782 500-nA $I_Q$, 150-mA, Ultra-Low Quiescent Current Low-Dropout Linear Regulator Data Sheet. Even though this device has 500-nA $I_Q$, it is not suited for applications where transient response is a critical parameter. When the TPS7A02 device is put under the same conditions, it results in the response as shown in Figure 4. As Table 1 shows, when the TPS7A02 device undergoes a similar load transient, the device shows vast improvement over the TPS782 device.

Figure 4. TPS7A02 Load Transient Response in TPS782 Conditions

It is also common to see devices address the disparity between $I_Q$ performance versus transient response by implementing several modes within an application. The typical scheme is to have an active-mode and a low-power mode. Some manufacturers dedicate a pin within the device to switch between these two states. Toggling the pin to HI will result in a larger current consumption and a faster transient response, versus LO which will result in lower current consumption and a slower transient response.

This combination is helpful in applications where the system is periodically brought from a low-power mode to an active mode. If the transition between these two states is very fast, then large undershoots could be experienced. However, adding an additional pin increases complexity within the system. Designers who use these devices must now not only consider when to toggle the pin for optimum performance, but also manage the routing on the board, which inadvertently increases the solution size. In other words, this is not the easiest solution to the problem.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>TPS782</th>
<th>TPS7A02</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_Q$</td>
<td>500 nA</td>
<td>25 nA</td>
</tr>
<tr>
<td>Overshoot</td>
<td>75 mV</td>
<td>+10 mV</td>
</tr>
<tr>
<td>Undershoot</td>
<td>−125 mV</td>
<td>−60 mV</td>
</tr>
<tr>
<td>Recovery Time</td>
<td>10 ms</td>
<td>5 µs</td>
</tr>
</tbody>
</table>
| $V_{IN} = 5.5$ V, $V_{OUT} = 3.3$ V, $I_{OUT} = 0$ mA to 10 mA, $C_{OUT} = 10$ µF

The TPS7A02 device transitions between active and low-power mode automatically without an additional pin. The dynamic biasing circuit detects any change on the output to ensure excellent transient response while maintaining nano-power quiescent current consumption.

The dynamic biasing increases the $I_Q$ as the DC load current increases and based on any error on the output, extending the bandwidth of the loop. The device response time across the output voltage range is constant because it uses a buffered reference topology, which keeps the control loop in unity gain at any output voltage.

Line transient performance is equally as important especially on noisy battery-powered rails powering motors where there can be an expected voltage increase. The TPS7A02 device also utilizes the dynamic biasing circuit to achieve a stable output when experiencing fast line transients. $V_{IN}$ transients figures on the TPS7A02 Data Sheet shows examples from typical battery voltages as well as when the device enters dropout conditions.

These features give the device a wide loop bandwidth during transients that ensures excellent dynamic performance while maintaining the ultra-low $I_Q$ of the device in steady-state conditions.

No Tradeoffs

Improving the current consumption of an LDO traditionally meant sacrificing the dynamic performance of your application. TI’s family of ultra-low $I_Q$ devices like the TPS7A02 and TPS7A03 provide the advantage of ultra-low nano $I_Q$ level, while maintaining excellent dynamic performance without the complexity of an additional pin.
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI's Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated