Power-supply margining circuit for LDOs using a precision DAC

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Design Goals

<table>
<thead>
<tr>
<th>Power Supply (VDD)</th>
<th>Nominal Output</th>
<th>Margin High</th>
<th>Margin Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>5V</td>
<td>3.3V</td>
<td>3.3V + 10%</td>
<td>3.3V – 10%</td>
</tr>
</tbody>
</table>

Design Description

A power-supply margining circuit is used for tuning the output of a power converter. This is done either to adjust the offset and drift of the power supply output or to program a desired value at the output. Adjustable power supplies like Low-Dropout Regulators (LDOs) and DC/DC converters provide a feedback or adjust input that is used to set the desired output. A precision voltage output digital-to-analog converter (DAC) is suitable for controlling the power-supply output linearly. The following image shows an example power-supply margining circuit. Typical applications of power-supply margining is in Test and Measurement, Communications Equipment, and Power Delivery.

Design Notes

1. Choose a DAC with the required resolution, pulldown resistor value, and output range.
2. Derive the relationship of the DAC output to $V_{\text{OUT}}$.
3. Choose $R_1$ based on typical current through the feedback circuit.
4. Calculate the start-up or nominal value of $V_{\text{DAC}}$ considering the power-down and power-up conditions of the DAC.
5. Select $R_2$ and $R_3$ such that the desired start-up output voltage is met along with the DAC output voltage range for the desired tuning range.
6. Calculate the margin low and margin high DAC outputs.
7. Choose a compensation capacitor to achieve the desired step response.
Design Steps

1. Select the LDO TPS79501 device for the calculations. The DAC53608 device is an ultra-low cost, 10-bit, 8-channel, unipolar output DAC suitable for such applications.

2. The output voltage of the power supply is given by:
   \[ V_{OUT} = V_{REF} + I_1 R_1 = V_{REF} + (I_2 + I_3) R_1 \]
   where
   - \( I_1 \) is the current flowing through \( R_1 \)
   - \( I_2 \) is the current flowing through \( R_2 \)
   - \( I_3 \) is the current flowing through \( R_3 \)

   DACs in this application typically include power-down mode, which includes an internal pulldown resistor at the voltage output. Hence, replacing the values of the currents in the previous equation yields:
   - When the DAC is in Power Down mode:
     \[ V_{OUT} = V_{REF} + \left( \frac{V_{REF}}{R_2} + \frac{V_{REF}}{R_3 + R_{PULL-DOWN}} \right) R_1 \]
   - When the DAC output is powered-up:
     \[ V_{OUT} = V_{REF} + \left( \frac{V_{REF}}{R_2} + \frac{V_{REF} - V_{DAC}}{R_3} \right) R_1 \]

   For DAC53608, \( R_{PULL-DOWN} \) is 10 kΩ. For the LDO part number TPS79501, the value of \( V_{REF} \) is 1.225V.

3. \( R_1 \) can be calculated by the following method.
   The current through the FB pin of TPS79501 is 1 µA. To make this current negligible, \( I_1 \) should be >> \( I_{FB} \). Choose \( I_1 \) to be 50 µA. Calculate \( R_1 \) as follows:
   \[ R_1 = \frac{V_{OUT} - V_{REF}}{I_1} = 41.5 \text{ kΩ} \]
   The nominal value of \( I_1 \) can be given by:
   - When the DAC is in Power Down mode
     \[ I_{1-Nom} = \frac{V_{REF}}{R_2} + \frac{V_{REF}}{R_3 + 10 \text{ kΩ}} \]
   - When the DAC output is powered-up
     \[ I_{1-Nom} = \frac{V_{REF}}{R_2} + \frac{V_{REF} - V_{DAC}}{R_3} \]
   The values of \( I_1 \) at Margin High and Margin Low outputs are given by:
   \[ I_{1-HIGH} = \frac{V_{OUT-HIGH} - V_{REF}}{R_1} = 57.95 \mu A \]
   \[ I_{1-LOW} = \frac{V_{OUT-LOW} - V_{REF}}{R_1} = 42.05 \mu A \]
   \[ I_{1-HIGH} - I_{1-Nom} = I_{1-Nom} - I_{1-LOW} = 7.65 \mu A \]

4. The nominal or startup value of \( V_{DAC} \) can be calculated using the following method:
   To make sure the 10-kΩ resistor does not impact when the DAC is transitioning from power-down to power-up, the power-up value for the DAC voltage can be calculated with:
   \[ \frac{V_{REF}}{R_3 + 10 \text{ kΩ}} = \frac{V_{REF} - V_{DAC}}{R_3} \]
   The previous equation can be further simplified to:
   \[ V_{DAC} = V_{REF} \left( \frac{10 \text{ kΩ}}{R_3 + 10 \text{ kΩ}} \right) \]
5. The values of $R_2$ and $R_3$ can be calculated as follows:

If the power-up or nominal value of $V_{DAC}$ is kept at one-third of $V_{REF}$, that is, 408.3mV, then $R_3$ will be $2 \times 10k\Omega = 20k\Omega$. $R_2$ can be calculated as:

$$\frac{V_{REF}}{R_2} + \frac{V_{REF}}{R_3 + 10k\Omega} = 50\mu A$$

Replacing the value of $R_3$, $R_2$ can be calculated to equal 133k$\Omega$.

6. Subtracting the Margin High and Nominal values of $I_1$, and the corresponding equations, we get

$$\frac{V_{REF} - V_{DAC}}{R_3} - \frac{V_{REF}}{R_3 + 10k\Omega} = 7.95 \mu A$$

So, the Margin High value of $V_{DAC}$ will be 249mV and similarly, the Margin Low value can be calculated as 567mV from the following equation:

$$\frac{V_{REF}}{R_3 + 10k\Omega} - \frac{V_{REF} - V_{DAC}}{R_3} = 7.95 \mu A$$

7. The step response of this circuit without a compensation capacitor has some overshoot and ringing as shown in the following curves. This kind of transient response can cause errors at the load circuits. To minimize this, use a compensation capacitor $C_1$. The value of this capacitance is usually obtained through simulation. A comparative output shows the waveforms with a compensation capacitor of 22pF.
DC Transfer Characteristics

Small Signal Step Response Without Compensation

Small-Signal Step Response With $C_1 = 22\text{pF}$
Design Featured Devices and Alternative Parts

<table>
<thead>
<tr>
<th>Device</th>
<th>Key Features</th>
<th>Link</th>
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<tbody>
<tr>
<td>DAC53608</td>
<td>8-channel 10-bit, I2C interface, buffered-voltage-output DAC</td>
<td><a href="http://www.ti.com/product/DAC53608">http://www.ti.com/product/DAC53608</a></td>
</tr>
<tr>
<td>DAC60508</td>
<td>8-channel, true 12-bit, SPI, voltage-output DAC with precision internal reference</td>
<td><a href="http://www.ti.com/product/DAC60508">http://www.ti.com/product/DAC60508</a></td>
</tr>
<tr>
<td>DAC60501</td>
<td>12-bit, 1-LSB INL, DAC with precision internal reference</td>
<td><a href="http://www.ti.com/product/DAC60501">http://www.ti.com/product/DAC60501</a></td>
</tr>
<tr>
<td>DAC8831</td>
<td>16-bit, ultra-low power, voltage output DAC</td>
<td><a href="http://www.ti.com/product/DAC8831">http://www.ti.com/product/DAC8831</a></td>
</tr>
<tr>
<td>TPS79501-Q1</td>
<td>Automotive catalog single output LDO, 500mA, adj.(1.2 to 5.5V), low-noise, high PSRR</td>
<td><a href="http://www.ti.com/product/TPS79501-Q1">http://www.ti.com/product/TPS79501-Q1</a></td>
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Design References
See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Link to Key Files

For direct support from TI Engineers use the E2E community e2e.ti.com

Revision History

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<th>Revision</th>
<th>Date</th>
<th>Change</th>
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<tbody>
<tr>
<td>A</td>
<td>September 2019</td>
<td>Updated circuit image on first page. Fixed typographical error in the first equation on the third page.</td>
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