Analog Engineer's Circuit: Data Converters
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Power-supply margining circuit for SMPS using a precision DAC

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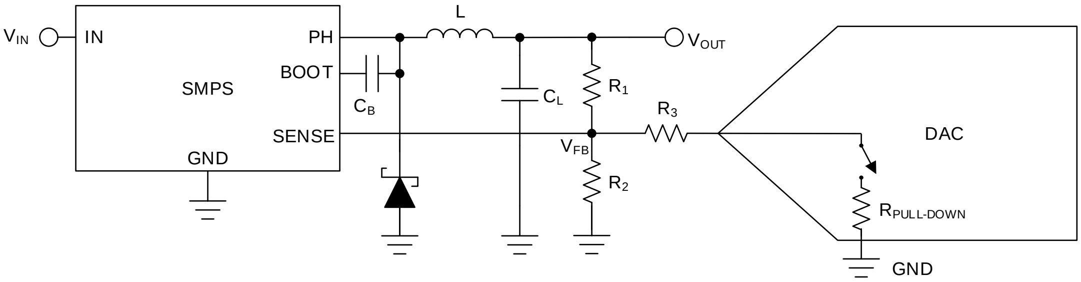
Design Goals

Power Supply (DAC VDD)	Nominal Output	Margin High	Margin Low
5V	5V	5V + 10%	5V – 10%

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 LDOs and DC/DC converters provide a feedback or adjust input that is used to set the desired output. A precision voltage output DAC is suitable for controlling the power-supply output linearly. An example power-supply margining circuit is shown in the following figure. Typical applications of power-supply margining is in Test and Measurement, Communications Equipment, and General Purpose Power Supply Modules.



Design Notes

1. Choose a DAC with required resolution, pulldown resistor value, and output range
2. Derive the relationship of the DAC output to V_{OUT}
3. Choose R_1 based on typical current through the feedback circuit
4. Calculate the start-up or nominal value of V_{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 get the desired step response

Design Steps

1. Select the switching DC/DC converter TPS5450 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

   $$V_{OUT} = V_{REF} + I_1 R_1 = V_{REF} + \left(I_2 + I_3\right) R_1$$

   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 DAC is in power-down mode:

   $$V_{OUT} = V_{REF} + \left(\left(\frac{V_{REF}}{R_2}\right) + \left(\frac{V_{REF}}{R_3 + R_{PULL-DOWN}}\right)\right) R_1$$

   - When DAC output is powered-up:

   $$V_{OUT} = V_{REF} + \left(\left(\frac{V_{REF}}{R_2}\right) + \left(\frac{V_{REF} - V_{DAC}}{R_3}\right)\right) R_1$$

   For DAC53608, $R_{PULLDOWN}$ is 10kΩ. For the LDO device TPS5450, the value of V_{REF} is 1.221V.
3. R_1 can be calculated with the following method:
   The current through the FB pin of the TPS5450 device is negligible. Select I_1 to be 50µA. So, R_1 is calculated as follows:

   $$R_1 = \frac{V_{OUT} - V_{REF}}{I_1} = 75.6\ k\Omega$$

   The nominal value of I_1 is given by:

   - When DAC is in power-down mode:

   $$I_{1-Nom} = \left(\frac{V_{REF}}{R_2}\right) + \left(\frac{V_{REF}}{R_3 + 10\ k\Omega}\right)$$

   - When DAC output is powered-up:

   $$I_{1-Nom} = \left(\frac{V_{REF}}{R_2}\right) + \left(\frac{V_{REF} - V_{DAC}}{R_3}\right)$$

   The values of I_1 at margin high and margin low outputs are given by:

   $$I_{1-HIGH} = \frac{V_{OUT-HIGH} - V_{REF}}{R_1} = 56.6\mu A$$

   $$I_{1-LOW} = \frac{V_{OUT-LOW} - V_{REF}}{R_1} = 43.4$$

   $$I_{1-LOW} = \frac{V_{OUT-LOW} - V_{REF}}{R_1} = 43.4$$
4. The nominal, or startup value of V_{DAC} is calculated by 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 is calculated with:

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

The previous equation is further simplified to:

$$V_{DAC} = V_{REF}\left(\frac{10\ k\Omega}{R_3 + 10\ k\Omega}\right)$$

5. The values of R_2 and R_3 are calculated as follows:

   If the power-up or nominal value of V_{DAC} is kept at 1/3 of V_{REF}, that is, 407mV, then R_3 is 2 × 10kΩ = 20kΩ. And, R_2 can be calculated as:

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

   Replacing the value of R_3, calculate R_2 = 131.3kΩ.

6. Subtracting the margin high and nominal values of I_1 and the corresponding equations yields:

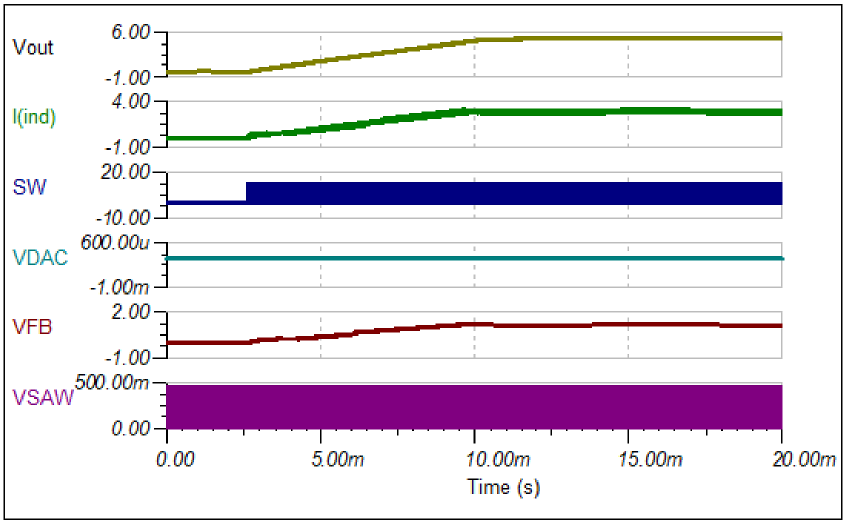
   $$\frac{V_{REF} - V_{DAC}}{R_3} - \frac{V_{REF}}{R_3 + 10\ k\Omega} = 6.6\mu A$$

   The margin high value of V_{DAC} is 275mV and similarly, the margin low value is calculated as 539mV using the following equation:

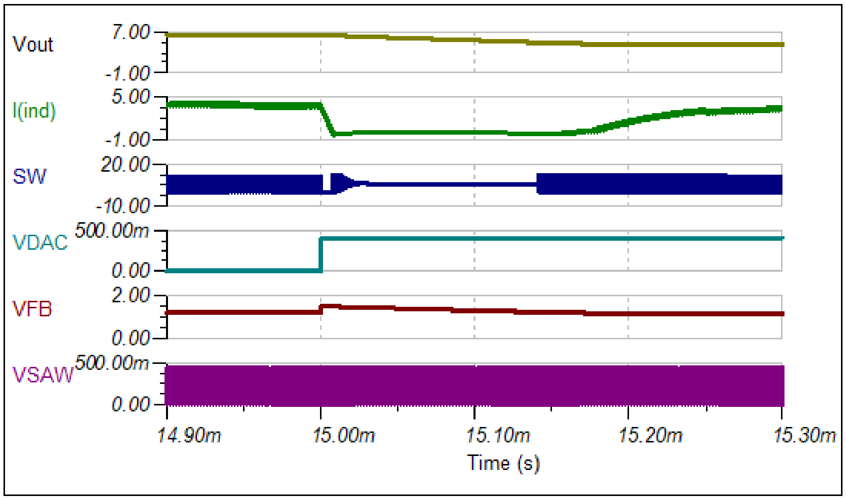
   $$\frac{V_{REF}}{R_3 + 10\ k\Omega} - \frac{V_{REF} - V_{DAC}}{R_3} - \ = 6.6\mu A$$

7. The step response of this circuit without a compensation capacitor causes the inductor current to reach its limit as shown in the following figure. This kind of surge can take the inductor into saturation. To minimize the surge, a compensation capacitor C_1 is used as the circuit diagram shows. The value of this capacitance is usually obtained through simulation. A comparative output shows the waveforms with a compensation capacitor of 10nF.

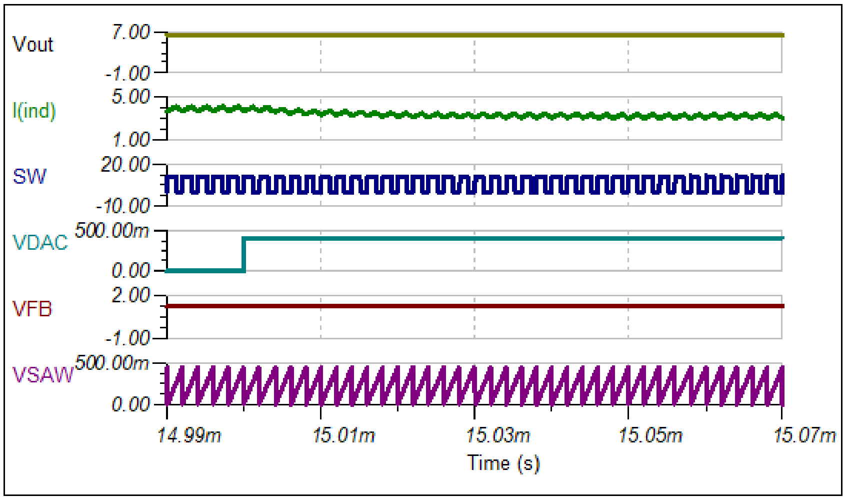
Output With DAC in Power Down Mode



Small-Signal Step Response Without Compensation



Small-Signal Step Response With C_1 = 10nF



Design Featured Devices and Alternative Parts

Device	Key Features	Link
DAC53608	8-channel 10-bit, I2C interface, buffered-voltage-output digital-to-analog converter (DAC)	http://www.ti.com/product/DAC53608
DAC60508	8-channel, true 12-bit, SPI, voltage-output DAC With precision internal reference	http://www.ti.com/product/DAC60508
DAC60501	12-bit, 1-LSB INL, digital-to-analog converter (DAC) with precision internal reference	http://www.ti.com/product/DAC60501
DAC8831	16-bit, ultra-low power, voltage output digital to analog converter	http://www.ti.com/product/DAC8831
TPS5450	5.5-V to 36-V input, 5-A, 500-kHz step-down converter	http://www.ti.com/product/TPS5450

Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Link to Key Files

TINA source files – http://www.ti.com/lit/zip/sbam416.

For direct support from TI Engineers use the E2E community

e2e.ti.com

Revision History

Revision	Date	Change
A	September 2019	Updated the circuit image on the first page.

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