Analog Engineer's Circuit

Power-Supply Margining Circuit for LDOs Using a Precision DAC

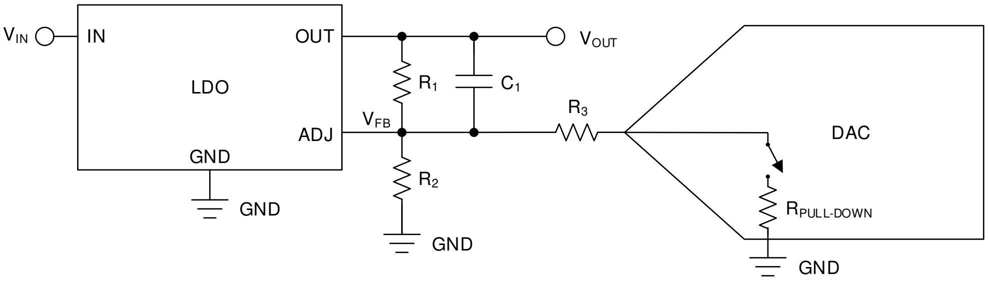
Uttama Kumar Sahu

Design Goals

Power Supply (VDD)	Nominal Output	Margin High	Margin Low
5V	3.3V	3.3V + 10%	3.3V – 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 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 designed 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_{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 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 designed 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:

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

- When the 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, $R_{PULL\text{-}DOWN}$ is 10kΩ. 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 1µA. To make this current negligible, I_1 should be >> I_{FB}. Choose I_1 to be 50µA. Calculate R_1 as follows:

$$R_1 = \frac{V_{OUT} - V_{REF}}{I_1} = 41.5\ k\Omega$$

The nominal value of I_1 can be given by:

- When the 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 the 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:

$$I_{1\text{-}HIGH} = \frac{V_{OUT\text{-}HIGH} - V_{REF}}{R_1} = 57.95\ \mu A$$

$$I_{1\text{-}LOW} = \frac{V_{OUT\text{-}LOW} - V_{REF}}{R_1} = 42.05\ \mu A$$

$$I_{1\text{-}HIGH} - I_{1\text{-}Nom} = I_{1\text{-}Nom} - I_{1\text{-}LOW} = 7.65\ \mu A$$

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:

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

The previous equation can be further simplified to:

$$V_{DAC} = V_{REF}\left(\frac{10\ \text{k}\Omega}{R3 + 10\ \text{k}\Omega}\right)$$

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 is 2 × 10kΩ = 20kΩ. R_2 can be calculated as:

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

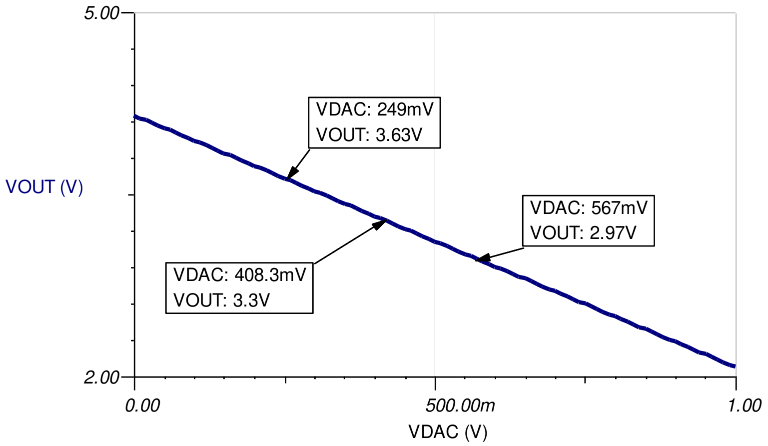
   Replacing the value of R_3, R_2 can be calculated to equal 133kΩ.
6. Subtracting the *Margin High* and *Nominal* values of I_1 and the corresponding equations, we get

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

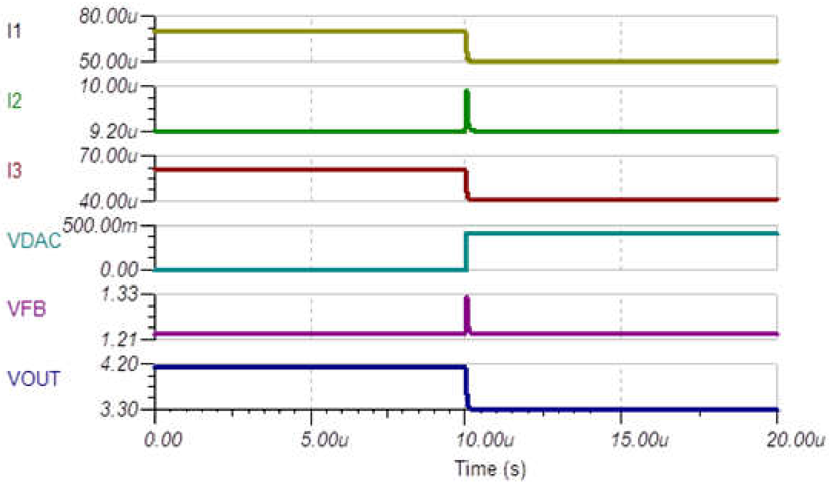
   So, the *Margin High* value of V_{DAC} is 249mV and similarly, the *Margin Low* value can be calculated as 567mV from the following equation:

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

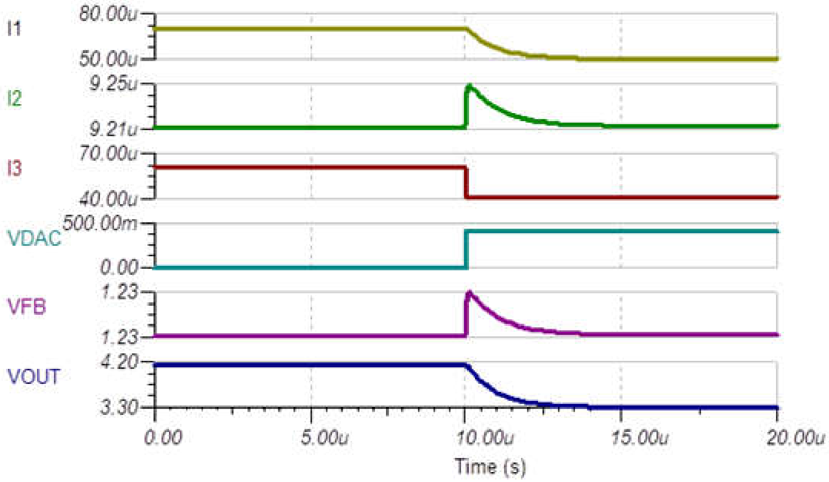
7. The step response of this circuit without a compensation capacitor has some overshoot and ringing as shown in the following curves. This kind of transient response can cause errors at the load circuits. To minimize this, use a compensation capacitor C_1. The value of this capacitance is usually obtained 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= 22pF

Design Featured Devices and Alternative Parts

Device	Key Features	Link
DAC53608	8-channel 10-bit, I2C interface, buffered-voltage-output DAC	10-Bit, 8-channel, I2C, voltage output DAC in tiny QFN package
DAC60508	8-channel, true 12-bit, SPI, voltage-output DAC with precision internal reference	True 12-Bit, 8-channel, SPI, Vout DAC in tiny WCSP package with precision internal reference
DAC60501	12-bit, 1-LSB INL, DAC with precision internal reference	True 12-bit, 1-ch, SPI/I2C, voltage-output DAC in WSON package with precision internal reference
DAC8831	16-bit, ultra-low power, voltage output DAC	16-Bit, Ultra-Low Power, Voltage Output Digital to Analog Converter
TPS79501-Q1	Automotive catalog single output LDO, 500mA, adj.(1.2 to 5.5V), low-noise, high PSRR	Automotive 500mA, adjustable low-dropout voltage regulator with enable

Design References

Texas Instruments, SBAM415 TINA source files, software support

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (September 2019) to Revision B (September 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document	1

Changes from Revision * (January 2019) to Revision A (September 2019)	Page
• Updated circuit image and equation	1

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