High-current voltage output circuit using a precision DAC

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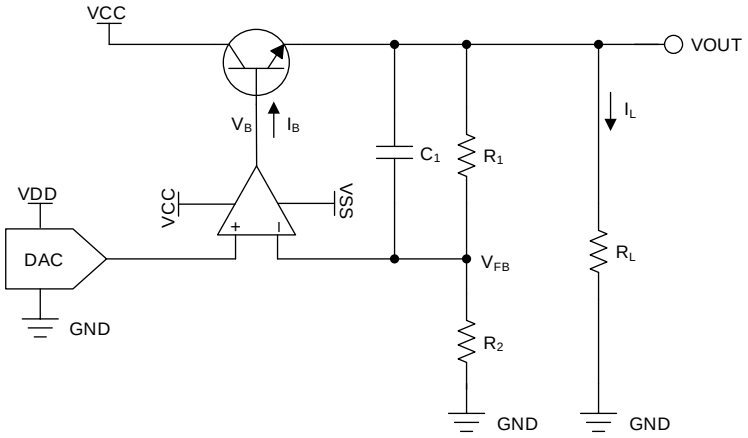
Design Goals

Power Supply	DAC Output	Voltage Output	Current Output
VCC: 24V, VSS: –5V, VDD: 5V	0V to 2.5V	0V to 5V	0A to 10A

Design Description

High-current voltage output can be obtained from a digital-to-analog converter (DAC) using a power amplifier at the DAC output. To have additional flexibility with amplifier performance like accuracy, bandwidth, and higher current, the circuit as shown in the following figure is more suitable. For example, power amplifiers typically have much higher output offset error compared to a precision amplifier. The DAC programs the output voltage along with the gain of the amplifier. The amplifier maintains the output voltage using negative feedback. The high current to the load is provided by the transistor. This circuit is useful in applications where components must be tested with different AC or DC voltage excitation such as memory and semiconductor test equipment, LCD test equipment, and others.



Design Notes

1. Choose a DAC with the required resolution and output range.
2. Choose an op amp with low offset and low drift to minimize error. Choose a part with sufficient gain-bandwidth product (GBW), as required by the output signal.
3. Choose R_1 and R_2 such that the desired output voltage is met along with the DAC output voltage, along with tolerance which maintains the desired accuracy.
4. Choose the compensation capacitor C_1 such that it is larger than the input capacitance of the op-amp inputs.
5. Choose a transistor that can provide the required load current and has a high h_{FE} so that the base current is sufficiently smaller than the output current limit of the op amp. A bipolar-junction transistor (BJT) Darlington pair or a high-power metal-oxide semiconductor field-effect transistor (MOSFET) are preferable.

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Design Steps

1. The DAC80501 device is a 16-bit, single-channel, high-performance precision DAC. The DAC80501 device is specified monotonic, by design, and offers excellent linearity of less than 1LSB. These devices include a 2.5V, 5ppm/˚C internal reference, giving full-scale output voltage ranges of 1.25V, 2.5V, or 5V.
2. The OPA227 operational amplifier combines low noise and wide bandwidth with high precision to make it the ideal choice for applications requiring both AC and precision DC performance. The OPA227 device is unity-gain stable and features high slew rate (2.3V/µs) and wide bandwidth (8MHz).
3. The transfer function of the output voltage is given by:

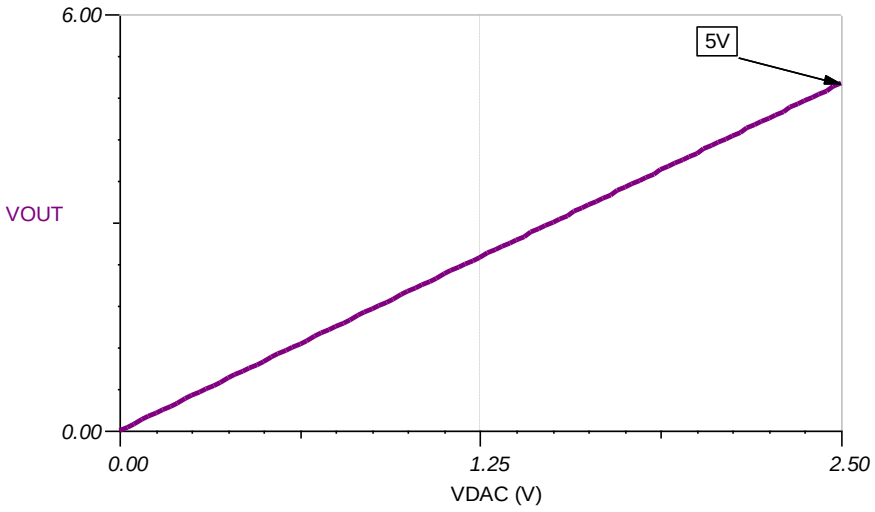
$$V_{OUT} = V_{DAC}\left(1 + \frac{R_1}{R_2}\right)$$

   To get an output voltage of 5V with a DAC output of 2.5V, for example, chose both R_1 and R_2 as 10kΩ. This keeps the quiescent current through the feedback network as 5V / 20kΩ = 250µA. This current works for this design because this design is for a high-output current. In case the output current is lower, the resistance values can be increased so that the quiescent current is negligible, compared to the output current.
4. The base current, I_B, for the transistor for a given load current I_L is given by:

$$I_B = \frac{I_C}{h_{FE}} = \frac{1}{h_{FE}}\left(I_L + \left(\frac{V_{OUT}}{R_1 + R_2}\right)\right)$$

   To get a maximum load current of 10A, the collector current (I_C) of the transistor is approximately 10A (ignoring 250-µA quiescent current). To keep I_B less than 20mA, h_{FE} should be greater than (10A / 20mA) = 500
5. In general, compensation capacitor C_1 is not set by fixed equations, but rather by choosing values while observing the output small-signal step response. Through simulation in this example, select C_1 ≥ 22pF.

DC Transfer Characteristics



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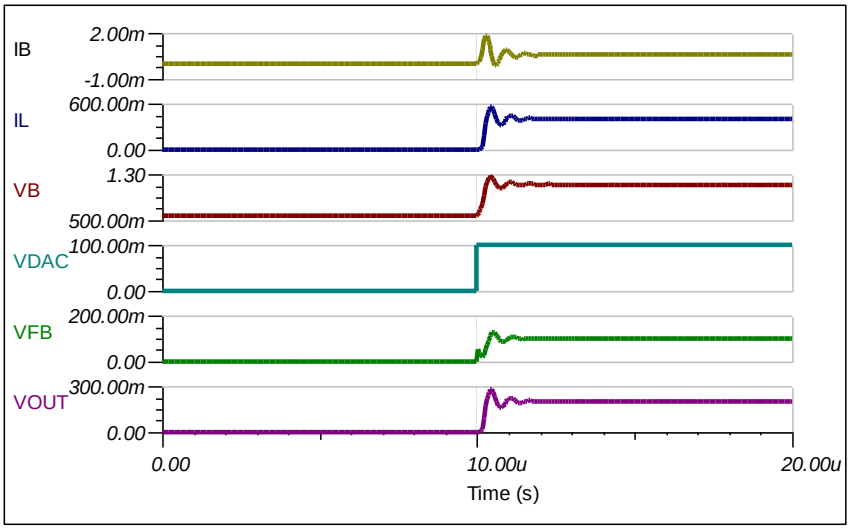
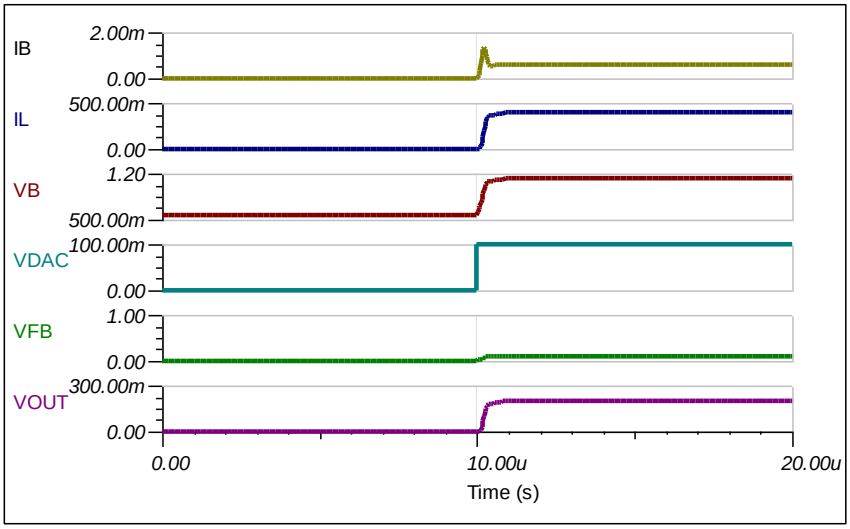
Small Signal Step Response Without Compensation



Small Signal Step Response With C_1 = 22pF



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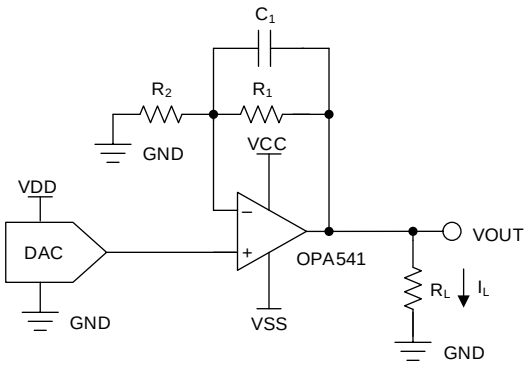
Alternative Design With Power Amplifier

The following figure depicts the simplified circuit diagram of an alternative design using a power amplifier. To achieve a high-current output from the DAC, use a power amplifier like the OPA541 device.. However, as previously mentioned, this circuit may have accuracy and bandwidth limitations. Depending on the system requirements, either of the circuit topologies can be used for generating high-current output. The output transfer function of this circuit is the same as the following figure.



Design Featured Devices and Alternative Parts

Device	Key Features	Link
DAC80501	16-bit, 1-LSB INL, digital-to-analog converter (DAC) with precision internal reference	http://www.ti.com/product/DAC80501
DAC8551	16-Bit, ultra-low glitch, voltage output, digital-to-analog converter	http://www.ti.com/product/DAC8551
DAC8811	16-bit, single-channel, serial input multiplying DAC with 0.5-µs settling time	http://www.ti.com/product/DAC8811
DAC8831	16-bit, ultra-low power, voltage output digital-to-analog converter	http://www.ti.com/product/DAC8831
OPA227	High Precision, Low Noise Operational Amplifiers	http://www.ti.com/product/OPA227
OPA541	High Power Monolithic Operational Amplifier	http://www.ti.com/product/OPA541
THS4011	290-MHz low-distortion voltage-feedback amplifier	http://www.ti.com/product/THS4011

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/sbam417.

For direct support from TI Engineers use the E2E community

e2e.ti.com

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