Unipolar voltage output DAC to bipolar voltage output circuit

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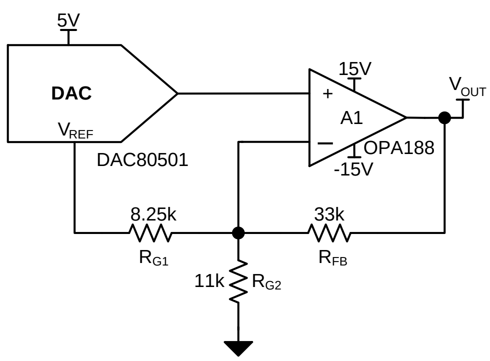
Design Goals

DAC Supply Voltage	Amplifier Supply Voltage	DAC Voltage	Output Voltage	Error
5V	±15V	0V–2.5V	±10V	<0.25% FSR

Design Description

The unipolar to bipolar output voltage circuit converts the voltage from a unipolar DAC into a bipolar voltage span. The circuit consists of a DAC, op amp, voltage reference, and 3 resistors to set the scale and span of the bipolar output voltage. This circuit is commonly used in PLC Analog Output Modules, Field Transmitters, and other applications requiring a programmable bipolar voltage.



Design Notes

1. Choose a DAC with low gain error, offset error, drift, and INL. A high-voltage op amp with low offset voltage and low offset voltage drift should be used.
2. Use precision 0.1% or better tolerance resistors with low temperature drift.
3. To minimize solution size a DAC with integrated reference may be used.

Design Steps

1. The voltage output based on DAC voltage, reference voltage, and resistors is given by:

$$V_{OUT} = \left(1 + \frac{R_{FB}}{R_{G1}} + \frac{R_{FB}}{R_{G2}}\right) V_{DAC} - \frac{R_{FB}}{R_{G1}} V_{REF}$$

2. Set the DAC voltage to zero to calculate ratio of R_{FB} and R_{G1} to create the desired negative full-scale output. Select standard resistor values to produce this gain.

$$\frac{V_{NegativeFS}}{V_{REF}} = \frac{R_{FB}}{R_{G1}} = \frac{10V}{2.5V} = \frac{33k\Omega}{8.25k\Omega}$$

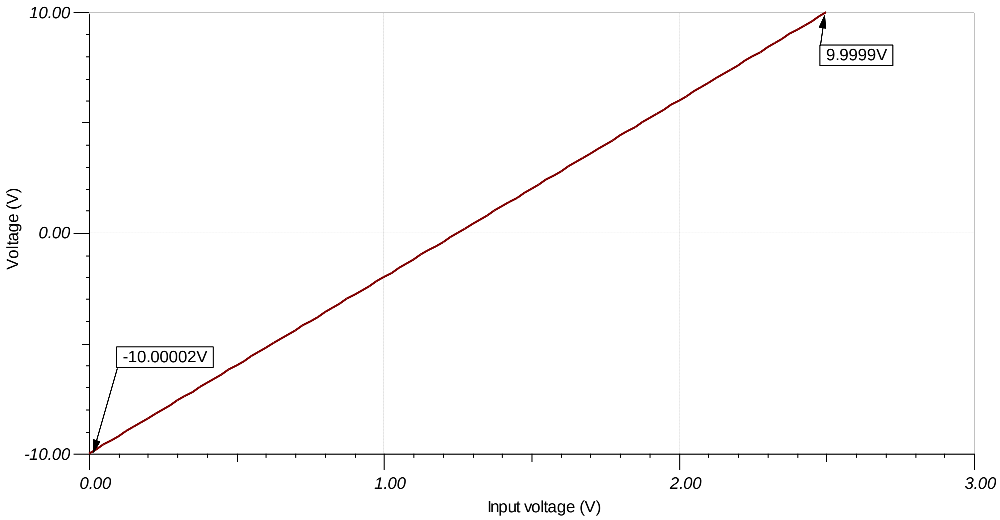
3. Calculate R_{G2} based on the full-scale range required, in this case 20V to produce ±10V range.

$$R_{G2} = \frac{R_{FB}}{\frac{V_{FSR}}{V_{DAC}} - \frac{R_{FB}}{R_{G1}} - 1} = \frac{33k\Omega}{\frac{20V}{2.5V} - \frac{33k\Omega}{8.25k\Omega} - 1} = 11k\Omega$$

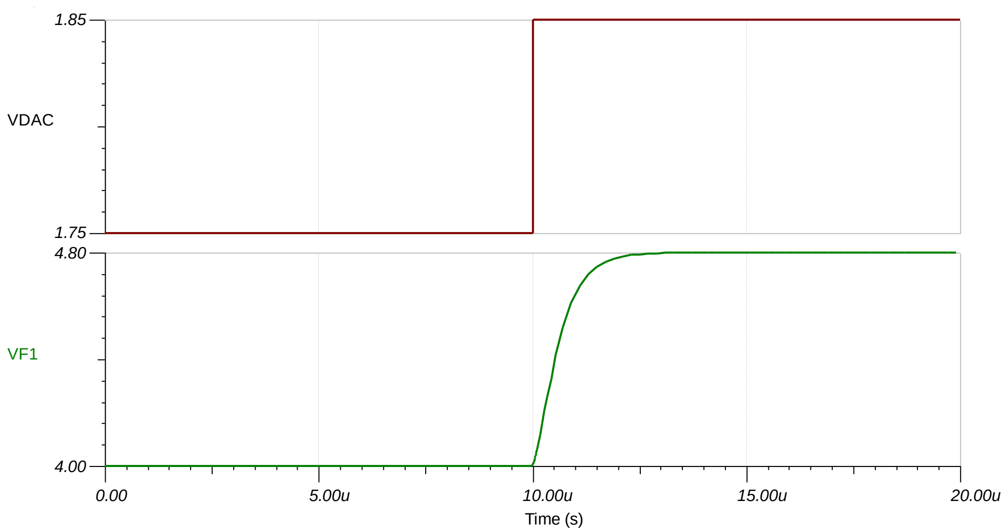
4. The output error can be approximated based on DAC TUE, amplifier offset voltage, resistor tolerance, and reference initial accuracy using root sum square (RSS) analysis.

$$\text{Output TUE}(\%FSR) = \sqrt{TUE^2_{DAC} + \left(\frac{V_{OS,Amplifier}}{FSR} \times 100\right)^2 + Tol^2_{R_{G1}} + Tol^2_{R_{G2}} + Tol^2_{R_{FB}} + Accuracy^2_{Ref}} = \sqrt{0.1^2 + \left(\frac{6uV}{2.5V} \times 100\right)^2 + 3 \times 0.1^2 + 0.1^2} = 0.224\%\ FSR$$

DC Transfer Characteristic



Small Signal Step Response



Devices

Device	Key Features	Link	Other Possible Devices
DACs			
DAC8560	16-bit resolution, single channel, internal reference, low power, 4 LSB INL, SPI, 2V to 5.5V supply	http://www.ti.com/product/DAC8560	http://www.ti.com/pdacs
DAC80501	16-bit resolution, 1LSB INL, Single-Channel, Voltage Output DAC with 5ppm Internal Reference	http://www.ti.com/product/DAC80501	http://www.ti.com/pdacs
DAC8830	16-bit resolution, single channel, ultra-low power, unbuffered output, 1 LSB INL, SPI, 2.7V to 5.5V supply	http://www.ti.com/product/DAC8830	http://www.ti.com/pdacs
Amplifiers			
OPA188	Low-Noise, Low Offset Voltage, RRO, Zero-Drift, ±2V to ±18V supply	http://www.ti.com/product/OPA188	http://www.ti.com/opamps
OPA196	Low-Power, Low Offset Voltage, RRIO, ±2V to ±18V supply	http://www.ti.com/product/TLV9001	http://www.ti.com/opamps
TLV170	Cost Sensitive, Rail-to-Rail Output, ±1.35V to ±18V supply	http://www.ti.com/product/OPA317	http://www.ti.com/opamps

Design References

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

Links to Key Files

TI Design TIDP125, *Bipolar ±10V Output from a Unipolar DAC for Industrial Voltage Drivers*.

Source Files for *Unipolar Voltage Output DAC to Bipolar Voltage Output* – http://www.ti.com/lit/zip/slac785.

For direct support from TI Engineers use the E2E community:

e2e.ti.com

Other Links:

Precision DAC Learning Center

http://www.ti.com/pdacs

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