Analog Engineer's Circuit

Unipolar Voltage Output DAC to Bipolar Voltage Output Circuit

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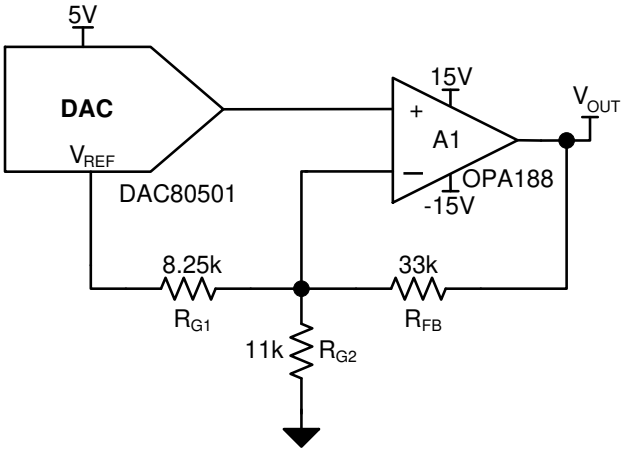
Design Goals

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 three resistors to set the scale and span of the bipolar output voltage. This circuit is commonly used in Analog output module, 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. Use a high-voltage op amp with low offset voltage and low offset voltage drift.
2. Use precision 0.1% or better tolerance resistors with low temperature drift.
3. Use a DAC with integrated reference to minimize solution size.

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.

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

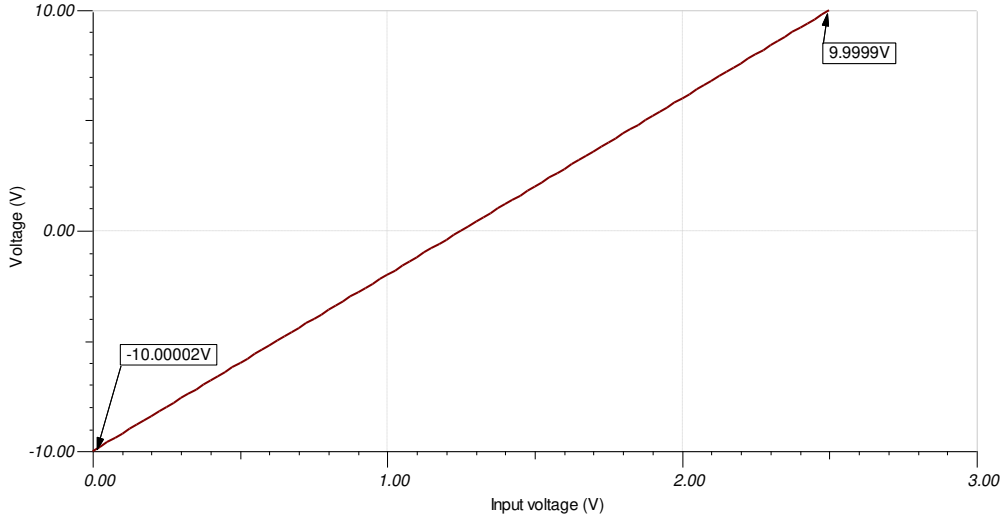
3. Calculate R_{G2} based on the full-scale range required, in this case 20V to produce ±10V range.

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

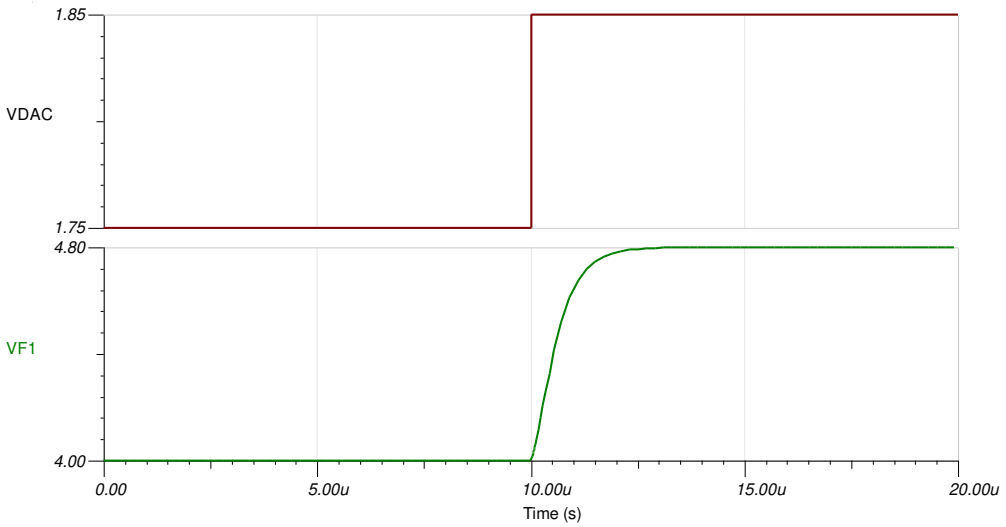
4. The output error can be approximated based on DAC TUE, amplifier offset voltage, resistor tolerance, and reference initial accuracy using root sum square (RSS) analysis.

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

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	16-bit, single-channel, low-power, ultra-low glitch, voltage output DAC with 2.5V, 2ppm/°C reference	Precision DACs (≤10 MSPS)
DAC80501	16-bit resolution, 1LSB INL, Single-Channel, Voltage Output DAC with 5ppm Internal Reference	True 16-bit, 1-ch, SPI/I2C, voltage-output DAC in WSON package with precision internal reference	Precision DACs (≤10 MSPS)
DAC8830	16-bit resolution, single channel, ultra-low power, unbuffered output, 1 LSB INL, SPI, 2.7V to 5.5V supply	16-bit, single-channel, ultra-low power, voltage output DAC	Precision DACs (≤10 MSPS)
Amplifiers			
OPA188	Low-Noise, Low Offset Voltage, RRO, Zero-Drift, ±2V to ±18V supply	Precision, Low-Noise, Rail-to-Rail Output, 36V Zero-Drift Operational Amplifier	Operational amplifiers (op amps)
OPA196	Low-Power, Low Offset Voltage, RRIO, ±2V to ±18V supply	One-channel, 1MHz, rail-to-rail input and output 1.8V to 5.5V operational amplifier	Operational amplifiers (op amps)
TLV170	Cost Sensitive, Rail-to-Rail Output, ±1.35V to ±18V supply	Low Offset, Rail-to-Rail I/O Operational Amplifier	Operational amplifiers (op amps)

Links to Key Files:

Texas Instruments, *Bipolar ±10V Output from a Unipolar DAC for Industrial Voltage Drivers*, TIPD125 tool

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