

## Unipolar voltage output DAC to bipolar voltage output circuit

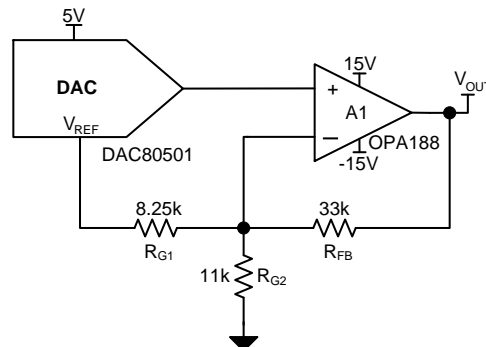
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### Design Goals

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:

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

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

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

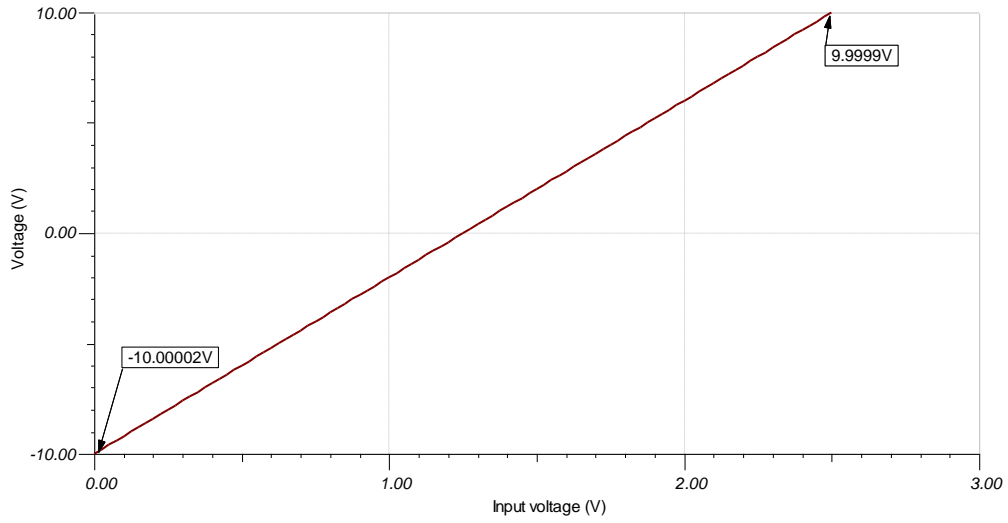
3. Calculate  $R_{\text{G2}}$  based on the full-scale range required, in this case 20V to produce  $\pm 10\text{V}$  range.

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

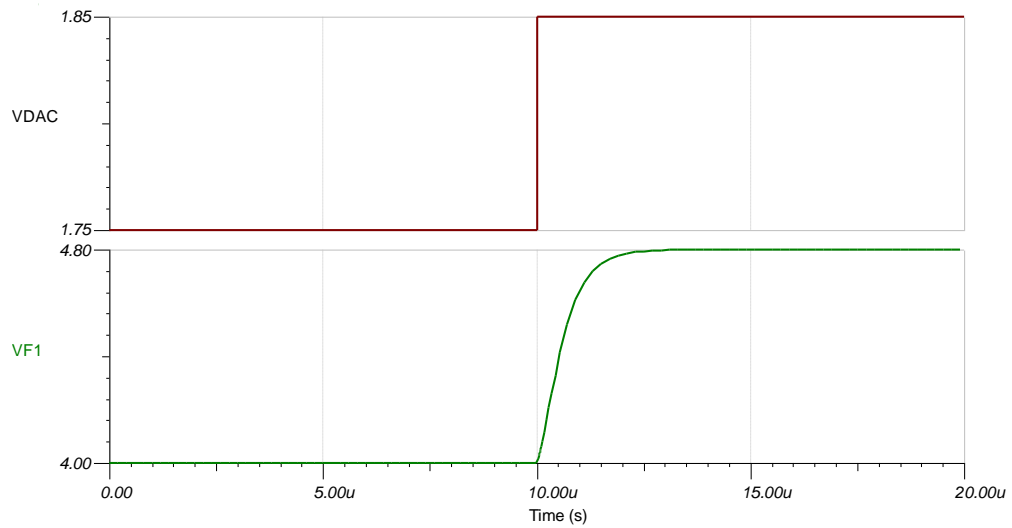
4. The output error can be approximated based on DAC TUE, amplifier offset voltage, resistor tolerance, and reference initial accuracy using root sum square (RSS) analysis.

$$\text{Output TUE}(\% \text{FSR}) = \sqrt{\text{TUE}_{\text{DAC}}^2 + \left( \frac{V_{\text{OS, Amplifier}}}{\text{FSR}} \times 100 \right)^2 + \text{ToI}_{\text{RG1}}^2 + \text{ToI}_{\text{RG2}}^2 + \text{ToI}_{\text{RFB}}^2 + \text{Accuracy}_{\text{Ref}}^2} = \sqrt{0.1^2 + \left( \frac{6\mu\text{V}}{2.5\text{V}} \times 100 \right)^2 + 3 \times 0.1^2 + 0.1^2} = 0.224\% \text{ FSR}$$

## DC Transfer Characteristic



## Small Signal Step Response



## Devices

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

### Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

### Links to Key Files

TI Design TIDP125, [Bipolar  \$\pm 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](http://e2e.ti.com)

### Other Links:

[Precision DAC Learning Center](#)

<http://www.ti.com/pdacs>

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