

Unipolar negative voltage source from unipolar DAC circuit

Paul Frost

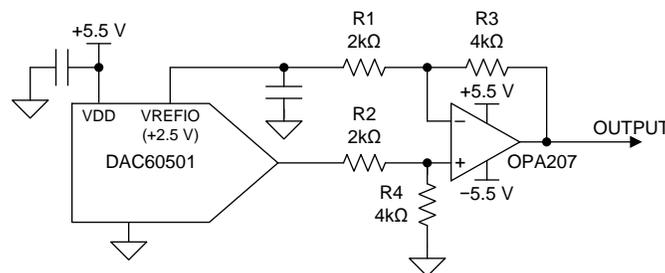
Design Goals

DAC Supply Voltage	Amplifier Supply Voltage	DAC Output Range	Output Voltage Range	Output Current Capability	Power-On Reset Output
5.5V	±5.5V	0V to 2.5V	–5V to 0V	±20mA	–5V

Design Description

This circuit shows how to convert a positive unipolar digital-to-analog (DAC) output to a negative unipolar output using only an external operational amplifier (op amp) and resistors. In many applications, such as [active antenna systems \(AAS\)](#) and [macro remote radio units \(RRU\)](#), a DAC output is used to bias the gate of gallium nitride (GaN) power amplifier (PA). For these amplifiers to be powered down, a negative potential must be applied to the gate. As such, it is beneficial to have the gate voltage be negative by default. PA biasing applications also require current output source and sink capability that usually exceeds that of most DACs.

These design goals are achieved by utilizing a voltage-output DAC that also features a reference. The DAC output and reference output are connected to differential amplifier with the reference connected to the inverting input. This enables the zero-scale output of the DAC to set the output of the amplifier to its negative full-scale value.



Design Notes

1. At power-on, the DAC output will assume a default value. This value can be configured in some devices by connecting a reset-select pin to a high or low potential, which selects a start-up value of zero-scale or mid-scale. In [AAS](#) designs, it is beneficial to start at zero-scale to ensure the PA is disabled. Other applications may require a DAC to start at mid-scale.
2. The amplifier selected must provide the output current required by the application. Rail-to-rail outputs allow the op amp power supplies to be minimized without clipping the desired output range of the circuit. In [AAS](#) applications, there is usually a capacitive load on the output as well, so capacitive load stability is important to consider.
3. The op amp must feature a bipolar supply, as the op amp inputs will always be greater than or equal to 0V in operation. The negative supply must be low enough to allow the output to reach its most negative value.

Design Steps

1. Select a DAC for the circuit based on initial on key requirements, such as the resolution, channel count, output accuracy, and power supply. These performance requirements are application dependant and can vary. However, a few additional items must be considered as well.

- The reference used to provide the offset of the differential amplifier will be required to source current. Current will flow from the reference through the resistors in the feedback network (R1 and R3) to the output of the amplifier. The maximum current would occur when the DAC output is at 0V and the output of the amplifier is at its most negative potential. The following equation shows how to calculate this current. If the current load is too great for the desired DAC reference, then a unity-gain buffer can be added to the circuit.

$$I_{REF-MAX} = \frac{V_{REF} - V_{OUT_MIN}}{R1 + R3}$$

- The output of DAC will also have to drive a resistive load, comprised of R2 and R4. The maximum required current drive capability is expressed in the following equation:

$$I_{DAC-MAX} = \frac{V_{DAC-MAX}}{R2 + R4}$$

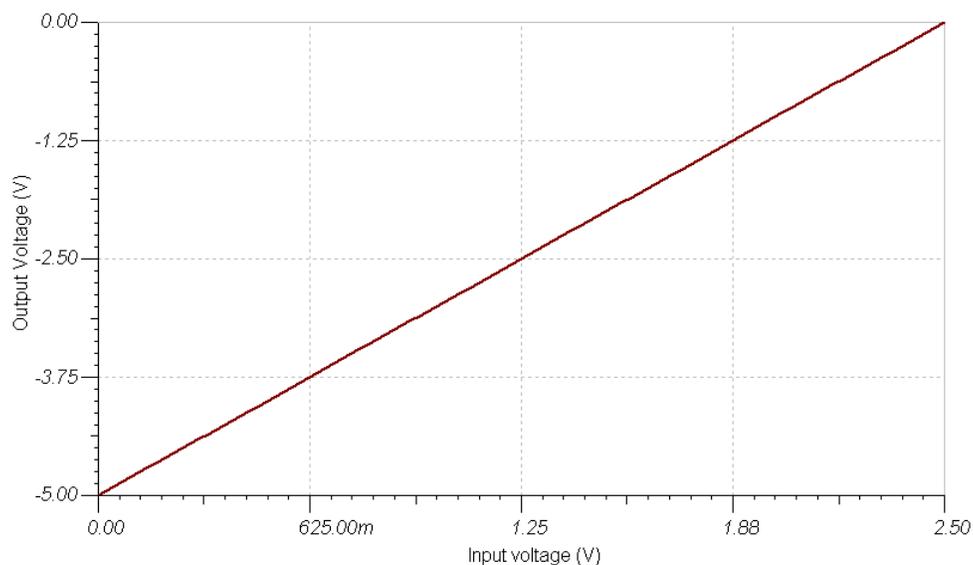
- DACs which have an output range from 0V to V_{REF} allow the resolution to be optimized for the negative output.
2. The output range of the system can be calculated using the following equation. This is assuming that R3 and R4 are equal and R1 and R2 are equal.

$$V_{OUT} = \frac{R3}{R1} (V_{DAC} - V_{REF})$$

3. Select resistor values to achieve a balance between output noise and power consumption. Lower resistor values will minimize the thermal noise of the resistors, but increase the power dissipation. The minimum resistance values are limited by the output drive capabilities of the DAC and reference output. The accuracy of the output transfer function is heavily dependent on the accuracy of the resistor ratios. High-accuracy resistors are recommended.

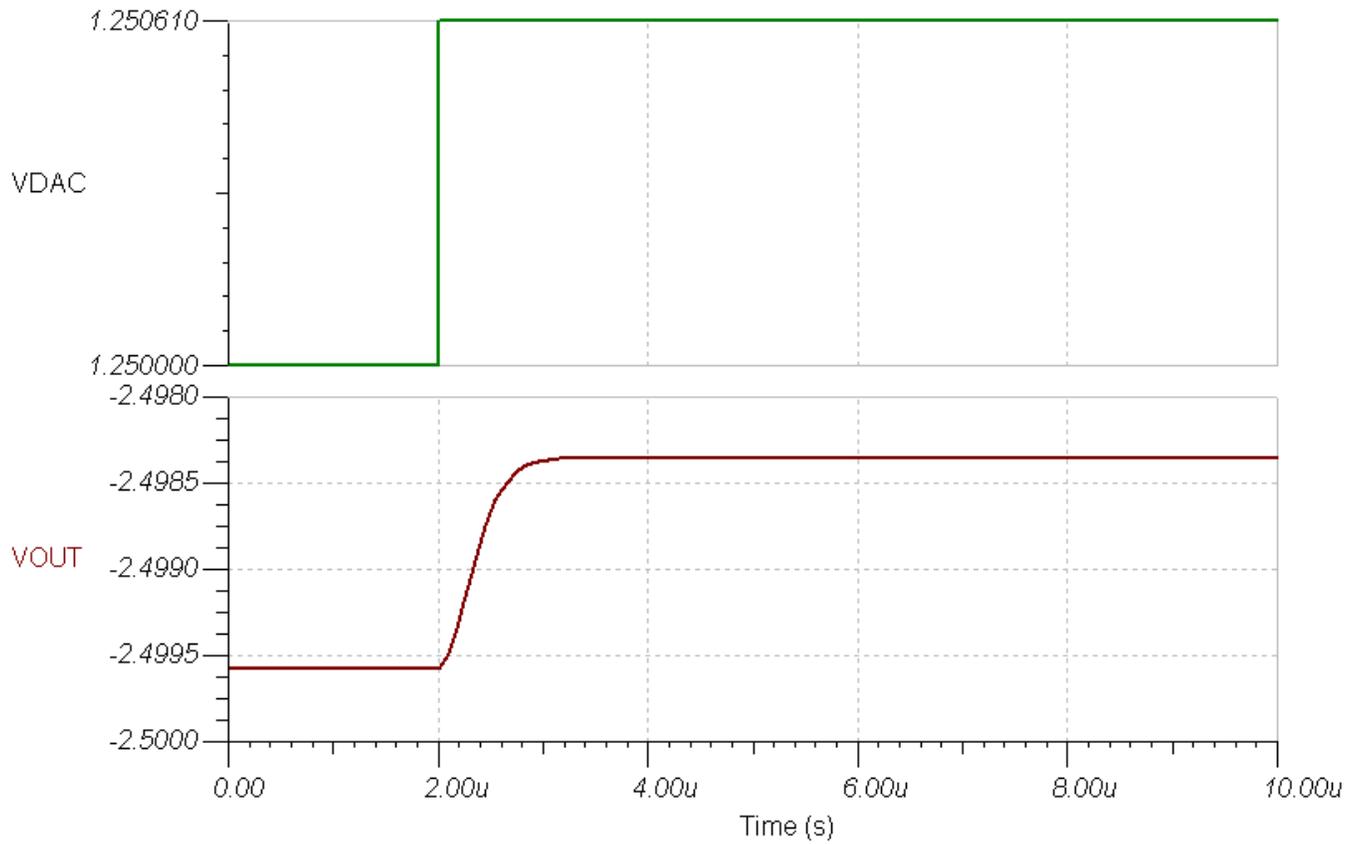
DC Transfer Characteristics

The following simulation shows the output transfer function of the circuit:



Small-Step Response

The following figure displays an LSB step response of the circuit with 15-pF load on the output.



Design References

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

Download the [companion simulation files for this circuit](#).

Design Featured Devices

Device	Key Features	Link	Other Possible Devices
DAC60501	12-bit, 1-LSB, voltage-output digital-to-analog converter with precision internal reference.	http://www.ti.com/product/DAC60501	Precision DACs from Texas Instruments
OPA207	Low-power, high-precision, low-noise, rail-to-rail output, operational amplifier	http://www.ti.com/product/OPA207	Precision Amplifier Overview

Other Links:

Learn more about using precision DACs at our [Precision DAC Learning Center](#).

Learn about [TI's precision DAC portfolio](#) and find more technical content.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated