Application Brief

Space-Grade, 100-krad, Programmable Negative Voltage Source (–5 V to 0 V) Circuit

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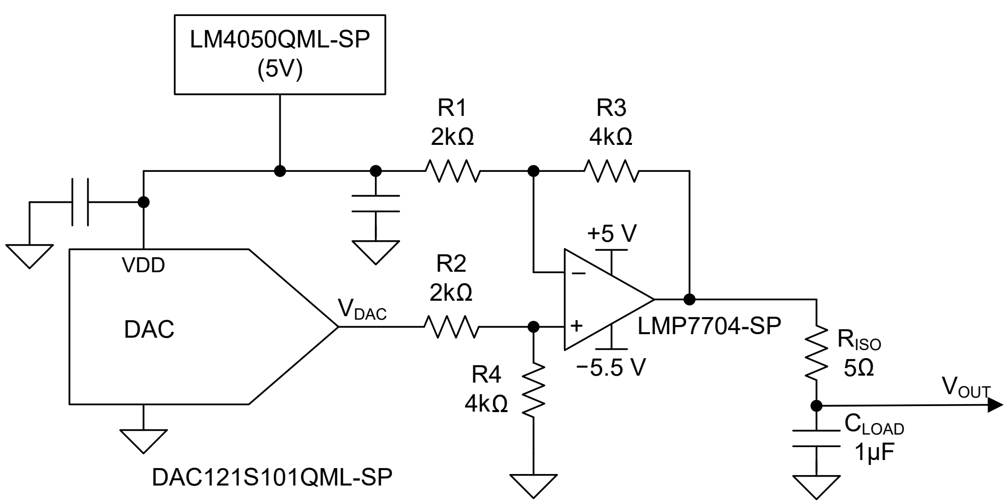
Design Goals

Parameter	Output
DAC Supply Voltage	5V
Amplifier Supply Voltage	10.5V (+5V, –5.5V)
DAC Output Range	0V to 2.5V
Output Voltage Range	–5V to 0V
Power-On Reset Output	–5V
Total Ionizing Dose (TID)	100 krad(Si)
Single-Event Latch-up (SEL) Immunity	85 MeV·cm^2/mg

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 communications payloads, and radar imaging payloads, there are RF power amplifiers at the end of the RF signal chain, and a DAC output can be used to bias the gate of a 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 the voltage-output DAC121S101QML-SP, an external reference, and the LMP7704-SP. The DAC output and reference output are connected to a 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. The LMP7704-SP supply voltage of 10.5V (+5V, –5.5V) was selected according the derating specifications provided by the National Aeronautics and Space Administration (NASA) in document EEE-INST-002 (April 2008) and the European Cooperation for Space Standardization (ECSS) in document ECSS-Q-ST-30-11C Rev.1 (4 October 2011). The documents specify an 80% and 90% derating of the absolute maximum supply voltage for linear ICs, respectively.
2. At power-on, the DAC output assumes 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 RF PA biasing 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.
3. 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 RF PA biasing applications, there is usually a capacitive load on the output as well, so capacitive load stability is important to consider.
4. 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 dependent and can vary. However, a few additional items must be considered as well:
   - The reference used to provide the offset of the differential amplifier is required to source current. Current flows from the reference through the resistors in the feedback network (R1 and R3) to the output of the amplifier. The maximum current occurs 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 add a unity-gain buffer to the circuit.

$$I_{REF\_MAX} = \frac{V_{REF} - V_{OUT,MIN}}{R1 + R3}$$

   - The output of the DAC also has 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. Calculate the output range of the system using the following equation. This is assuming that R3 and R4 are equal and R1 and R2 are equal.

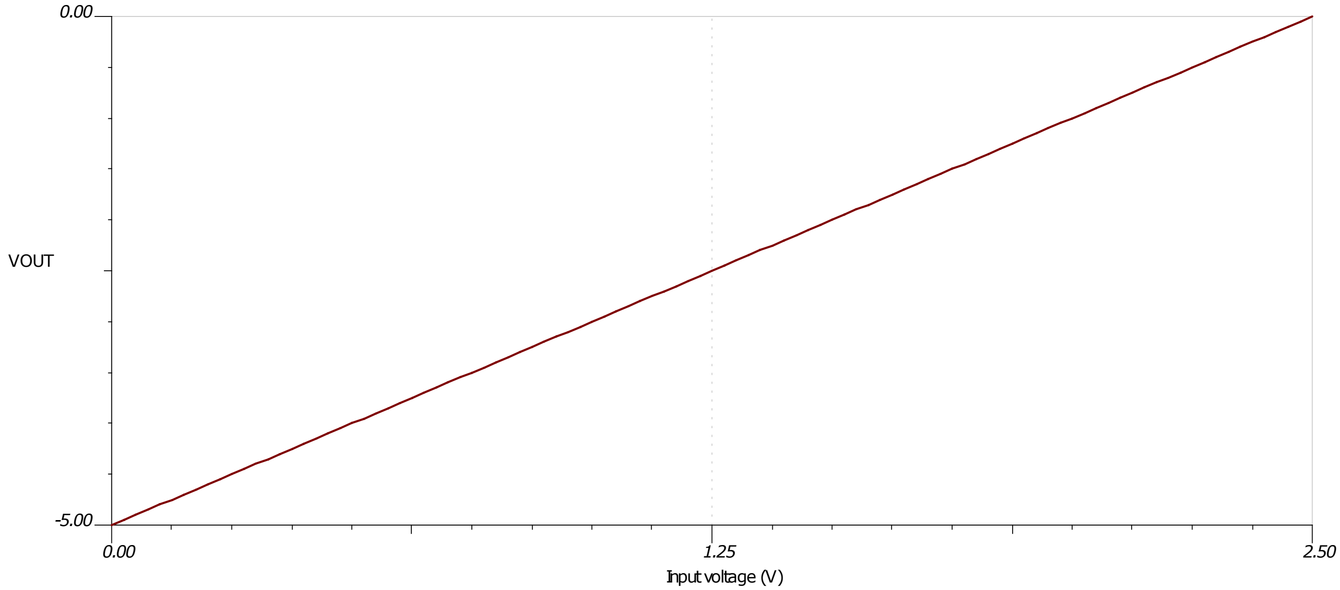
$$V_{OUT} = \frac{R3}{R1}\left(V_{DAC} - V_{REF}\right)$$

3. Select resistor values to achieve a balance between output noise and power consumption. Lower resistor values 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.

Design Simulations

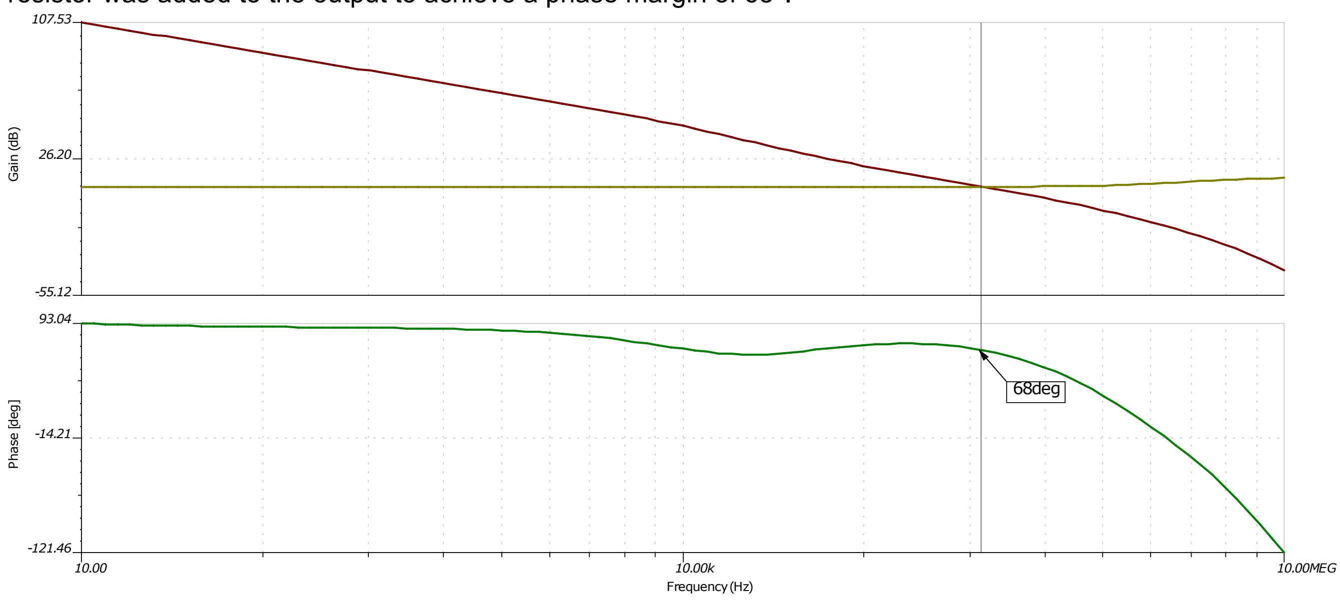
DC Transfer Characteristics

The following simulation shows the output transfer function of the circuit. The voltage output of the DAC is varied from 0V to 2.5V.



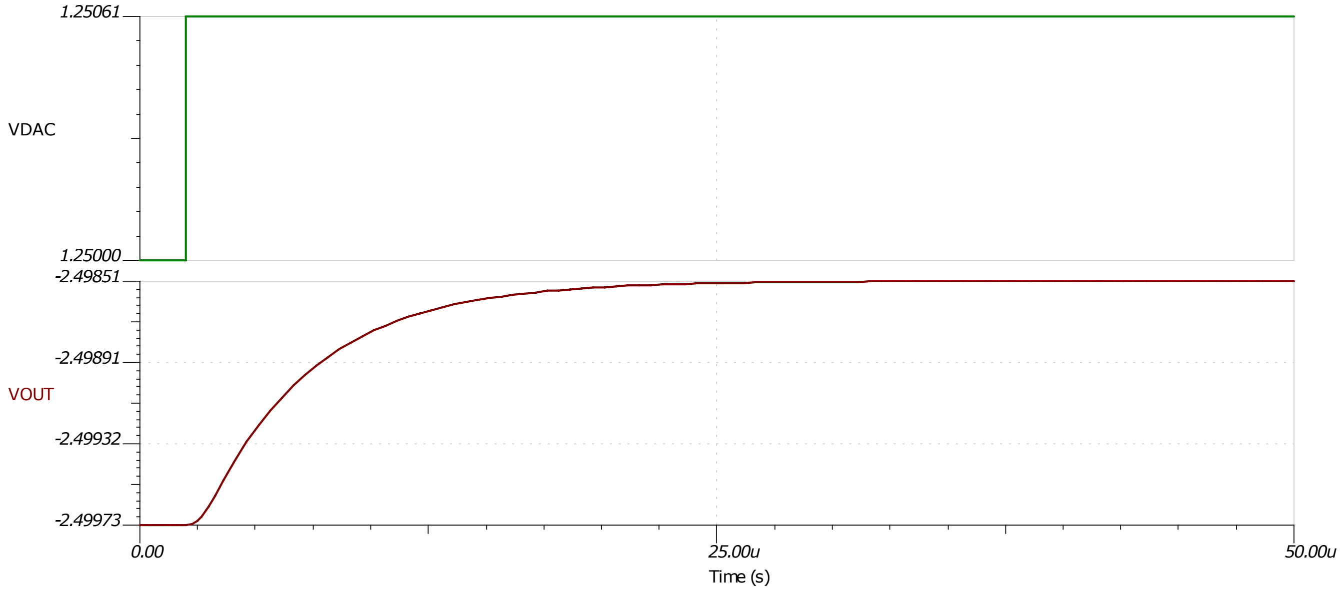
Stability

The following figure displays a stability simulation of the circuit with a 1-μF load on the output. A 5-Ω R_{ISO} resistor was added to the output to achieve a phase margin of 68°.



Small-Step Response

The following figure displays an LSB step response of the circuit with a 1-µF load on the output. The 5-Ω R_{ISO} resistor from the previous section provides a stable response.



Design References

Unipolar negative voltage source from unipolar DAC circuit

Additional Resources:

- Learn more about using precision DACs at our Precision DAC Learning Center.
- Learn about TI's precision DAC portfolio and find more technical content.

For direct support from TI Engineers use the E2E community: e2e.ti.com.

Design Featured Devices

Device	Key Features	Link
DAC121S101QML-SP	Radiation Hardened 12-Bit Micro Power Digital-to-Analog Converter With Rail-to-Rail Output	https://www.ti.com/product/DAC121S101QML-SP
LMP7704-SP	Low-power, high-precision, low-noise, rail-to-rail output, operational amplifier	https://www.ti.com/product/LMP7704-SP
LM4050QML-SP	Radiation-hardness-assured (RHA) 2.5-V or 5-V shunt voltage reference	https://www.ti.com/product/LM4050QML-SP