Application Report

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Low-Noise Negative Reference Design with REF5025

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ABSTRACT

This document describes using the REF5025 to generate high-accuracy, low-noise negative reference voltage output. The REF5025 is mainly adapted to data converters, where it can be necessary to have a negative reference voltage. A key consideration of designing signal paths with data converters is minimizing noise level, which improves image quality in medical applications that use data converters like the DAC8801, along with AFE58x8. This application report explains two approaches for generating negative a reference voltage that minimizes the reference output noise.

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1 Introduction

In general, a voltage reference is an electronic device that produces a fixed voltage, regardless of the following:

- Loading on the device
- Power supply variations
- Temperature changes
- Passage of time

Voltage references are typically seen with the following devices and systems:

- Analog-to-digital (ADC) converters
- Digital-to-analog (DAC) converters
- Power supplies
- Other measurement systems

The REF50xx is a family of low-noise, low-drift, very high-precision voltage references. This document provides a comprehensive overview of voltage reference basics, application design, and negative reference output configuration. Voltage references are one of the key components in data conversion systems. They enable an ADC or DAC to read accurate values, and are used in various high-accuracy data converting applications. Modern active components, such as A/D and D/A converters and operational amplifiers, typically do not require a negative supply voltage. However, there are still some cases where a negative voltage is required, including high-performance, high-speed A/D and D/A converters. TI's low-noise analog front ends (AFEs) have a time-gain control feature that can alter the receiver gain as a function of time. These AFEs can support ultrasound scanner applications.

2 Voltage Reference Architecture

2.1 Shunt or Series Reference

Voltage references are a major building block in data conversion systems. Understanding their specifications and how they contribute to error, is necessary for selecting the right reference for the application. Figure 1 shows two available voltage reference topologies: series and shunt. A series reference provides a load current through a series transistor, located between VIN and VREF(Q1). It is basically a high-precision, low-current linear regulator. A shunt reference regulates VREF by a shunting excess current to ground through a parallel transistor (Q2).

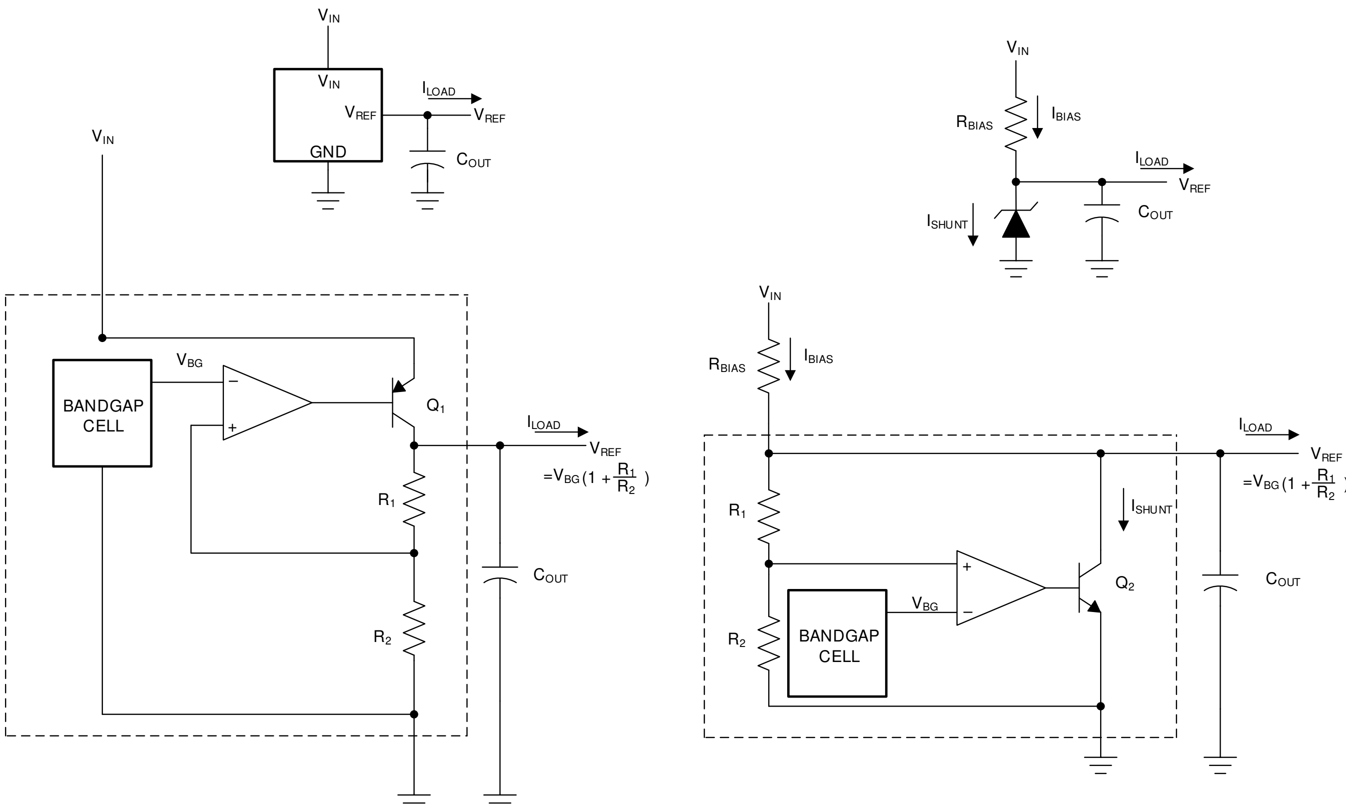

Figure 1. Circuit Symbols and Simplified Schematics of Series and Shunt Architectures

2.2 *Choosing the Best System Reference*

Table 1 describes the advantages and disadvantages of each architecture.

Table 1. Series Versus Shunt Architecture

	SERIES REFERENCE	SHUNT REFERENCE
ADVANTAGES	• Significantly lower power dissipation • Generally higher precision • Low IQ and low drop out	• Wide VIN tolerance with proper resistor selection • Can create negative, or floating, reference voltage • Inherent current sinking
DISADVANTAGES	• Limited max VIN	• VIN current fixed at max load • No shutdown mode
APPLICATIONS	• Medical • Factory automation • Grid • Test equipment	• Isolated power supplies • Automotive adapters

3 Key Specifications for Voltage Reference

As with all ICS, voltage references have standardized design parameters for determining the right part. The following are key specifications listed in order of importance:

3.1 Temperature Coefficient

The variation in VREF over temperature is defined by its temperature coefficient (TC, also referred to as “drift”) in units of parts-per-million per degree Celsius (ppm/℃). It is convenient to represent the dependence of the reference voltage temperature as a polynomial for the sake of discussion. The REF50xx is designed for minimal drift error, defined as the change in output voltage over temperature.

3.2 Initial Accuracy

The initial accuracy of the VREF indicates how close the stated nominal voltage is to the reference voltage, which is assured to be at room temperature under state bias conditions. It is typically specified as a percentage, and ranges from 0.01% to 1% (100 – 10 000 ppm). For example, a 2.5-V reference with 0.1% initial accuracy must be between 2.4975 V and 2.5025 V when measured at room temperature. The importance of the initial accuracy mainly depends on whether the data conversion system is calibrated.

3.3 0.1–10 Hz Peak-to-peak Noise

The internally generated noise of a voltage reference causes a dynamic error that degrades the signal-to-noise ratio (SNR) of a data converter. This error reduces the estimated number of bits of resolution (ENOB). Usually, data sheets provide separate specifications for low and high-frequency noise. Broadband noise is typically specified as a RMS value in microvolts over the 10-kHz to 10-kHz bandwidth. Broadband noise is the less troublesome of the two, as it can be reduced with a large VREF bypass capacitor. Depending on the signal bandwidth the designer is interested in, broadband noise may or may not be important in a given application.

3.4 Thermal Hysteresis and Long-term Stability

Thermal hysteresis is the shift in VREF due to thermal excursions. It is specified in parts-per-million. A thermal excursion is defined as an excursion from room temperature to a minimum or maximum temperature then back to room temperature. The temperature range (commercial, industrial, or extended) and definition of thermal excursion can vary by manufacturer, which makes direct comparisons difficult. Long-term stability describes the typical shift in VREF after 1000 hours (or six weeks) of continuous operation under nominal conditions. It is meant to give the designer a rough idea of the reference voltage stability over the life of the application.

3.5 Load and Line Regulation

Load regulation is the measure of the variation in VREF as a function of load current. It is specified either as a percentage, or in parts-per-million per milliamp (ppm/mA). It is calculated by dividing the relative change in VREF at the minimum and maximum load currents by the range of the load current. Load regulation depends on both the reference design and the parasitic resistance separating it from the load, so the reference must be placed as close to the load as the PCB layout allows.

The impedance of the reference input is large enough (> 10 kΩ) on many data converters that load regulation error may not be significant. Maximum load current information can be found in ADC or DAC data sheets as either a minimum reference pin resistance (RREF), or a maximum reference current (IREF). In situations where the reference is buffered with a high-speed op amp, load regulation error can usually be ignored. Line regulation applies only to series voltage references, and is the measure of the change in the reference voltage as a function of the input voltage. The importance of line regulation depends on the tolerance of the input supply, and may not contribute significantly to the total error in when the input voltage tolerance is within 10% or less.

As with line regulation, PSRR importance depends on input supply specifics. For example, the PSRR can be critical if the VIN is noisy due to a switching regulator, is sensitive to EMI, and is subject to large load transients.

4 Method of Negative Output Design and Noise Analysis

To generate a positive voltage output on the DAC8801, a negative voltage reference is needed for the data converter. Generally, the low-noise performance on the data conversion signal path is required on medical image application. For applications that require a negative and positive voltage, the data sheet specifies the typical 0.1-Hz to 10-Hz voltage noise for each member of the REF50xx series. Since there is a focus on noise immunity, some REF50xx series reference have a TRIM/NOISE REDUCTION (NR) pin to enhance performance. As shown in Figure 2, the TRIM/NR pin can adjust the output voltage by up to ±15 mV and create a low-pass filter. As shown in Figure 2, this process uses a capacitor to decrease the overall noise measured on VOUT. Note that increasing the capacitor size continues to improve noise performance but increases start-up time. When analyzing noise, inject an external disturbance signal accordingly.

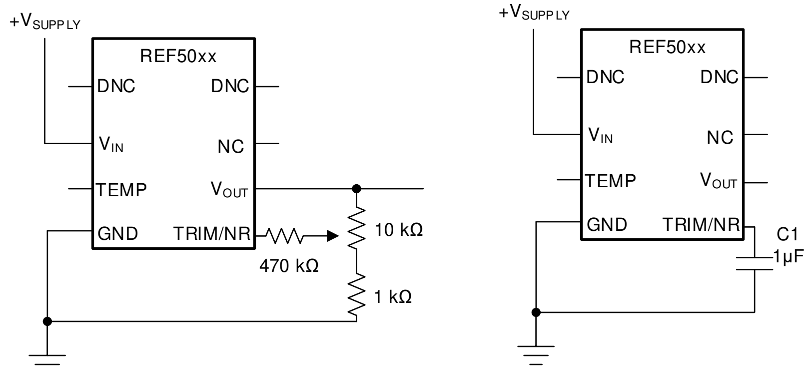

Figure 2. VOUT Adjustment (Left) and Noise Reduction (Right) Using TRIM/NR Pin

4.1 Voltage Inverting by Level Shift using REF5025 and OPA192

For the DAC8801 reference input to generate positive DAC output, about -2.5-V negative output reference and negative output circuit configuration must be created first. Figure 3 shows a circuit that inverts output voltage from positive to negative. The output is feedback to the op amp input. The ground level on the REF5025 is tied to the op amp output, which shifts the positive level to negative. This is implemented by using an inverting circuit for a negative reference output. According to the noise level simulation graph in Figure 3, the output is -2.5 V. With this circuit, VREF negative output noise is about 210 nV/rtHz at 10 KHz.

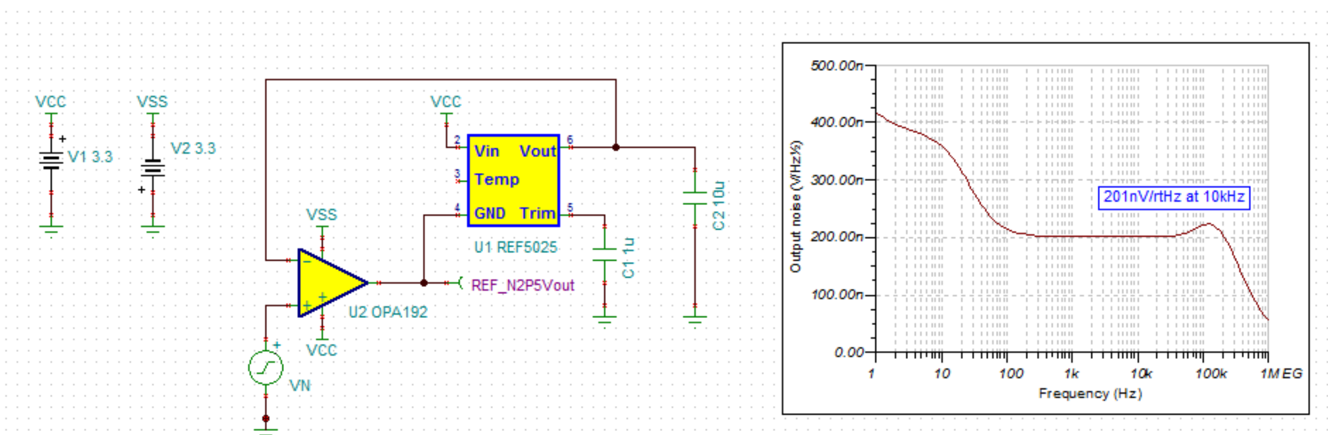

Figure 3. Level Shifting Circuit and Noise Analysis Result

4.2 Using a Buffer to Generate Negative Reference Output

Figure 4 shows how to use the buffer to generate a negative output. The buffer input from the REF5025 output is positive, and the op amp inverts the voltage level from positive to negative. For better noise immunity, select a low-noise op amp. The OAP192 is applied to this buffer circuit. With this circuit, the VREF negative output noise is about 271 nV/rtHz at 10 kHz, which is slightly higher than Figure 3 because of the additive noise by OPA192 and external passive components for configuring of buffer.

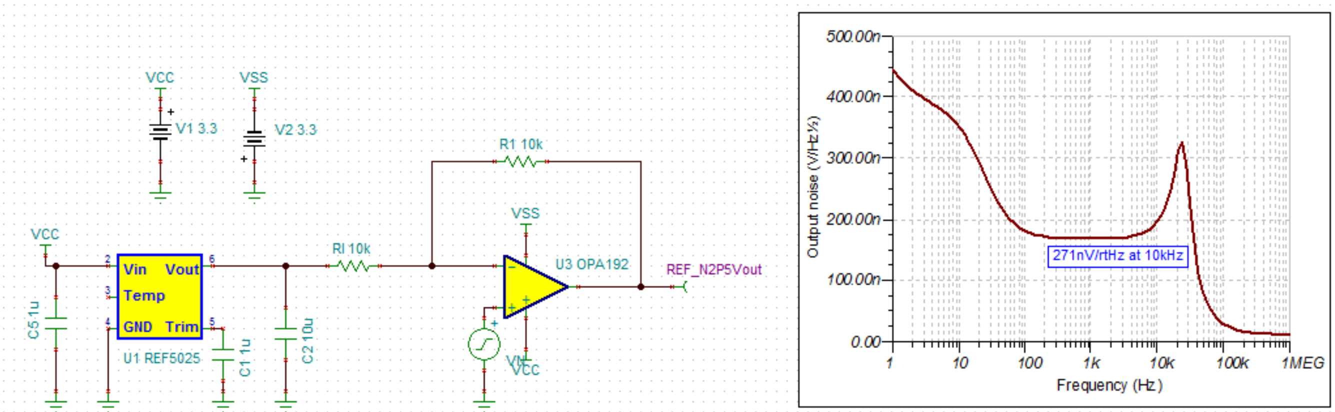

Figure 4. The Circuit for Buffer Use and Noise Simulation

4.3 A Way to Minimize the Noise

In Figure 3, the low-frequency filter is applied below the circuit to minimize output noise. To further reduce output noise at the low-frequency range, apply the filter at a low cut-off frequency. Figure 5 shows the noise analysis simulation results for a circuit using a very low cut-off filter between the reference and an ADC or DAC. The noise level is lower compared to a circuit without a low-pass cut-off filter. VREF negative output noise is about 13.8 nV/rtHz at 10 kHz. Though improved compared to Figure 4, noise can be further minimized by adding a low-frequency filter.

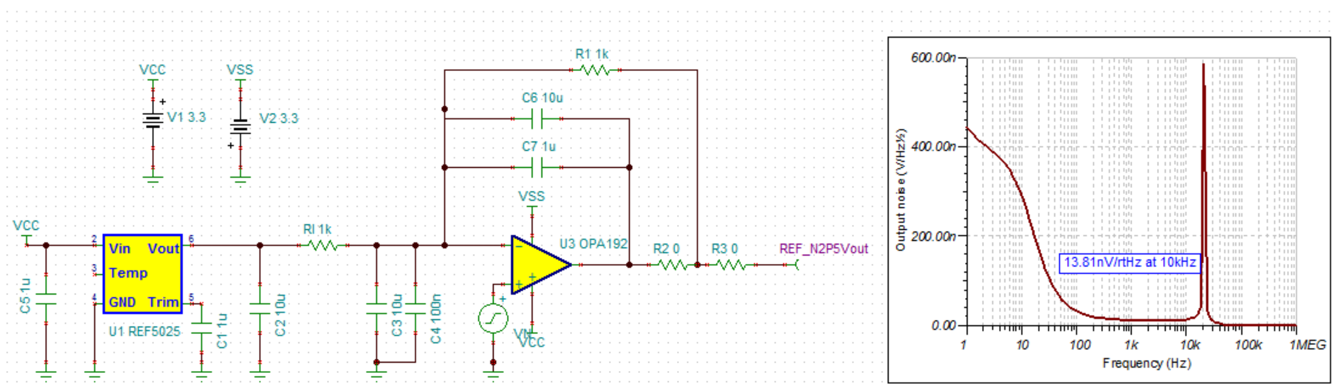

Figure 5. Adding Low-Frequency Filter to Minimize Output Noise

5 Conclusion

Usually a voltage reference is a key building block in data conversion system, and some converters like the DAC8801 need negative reference voltage to generate positive DAC output. Designers can make various reference voltage circuits based on the data converter type and conversion range, which depend on system requirements. This application report describes two kinds of negative reference output circuits with the REF5025 and OPA192. One method uses a level-shift invert, while the other uses a buffer to generate a negative output. The noise analysis results for each case can also be viewed with the noise analysis tool in TINA. Figure 5 introduces the best way to minimize noise. As a result, a negative reference circuit with low-noise, and high-performance voltage output is achievable on the REF5025.

6 References

1. Texas Instruments, *REF5025 Low-Noise, Very Low Drift, Precision Voltage Reference Data Sheet* (SBOS410)
2. Texas Instruments, *Voltage Reference Selection Basics White Paper* (SLPY003)
3. Texas Instruments, *TI Designs: 2.3-nV/√ Hz, Differential, Time Gain Control DAC Reference Design for Ultrasound* (TIDUD38)