Application Note

Demystifying Design Challenges in Ultra-Low Noise, High-Fidelity Waveform Generation Using 20-Bit DACs

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DAC

ABSTRACT

This application note explores the applications and their requirements for high-fidelity waveform generation. The DAC11001B, 20-bit resolution, highly accurate, ultra-low noise, low glitch, and exceptional signal chain THD performance are reviewed and showcased. Also, the competitive analysis report helps the system designer understand DAC11001B's performance benefits.

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1 Introduction

Strides have been made over time to improve the accuracy and overall performance of Precision DACs while also providing higher resolutions. In the past, Precision DACs were DACs that performed at speeds less than or equal to 10 MSPS and focused on being highly accurate rather than speed. Due to this focus, precision DACs have been limited by resolution and have only seen superior linearity at around 16-bits.

Texas Instruments continues to invest in all of the digital-to-analog converter (DAC) markets, and recently released its first 20-bit, resistor-ladder based precision DAC, the DAC11001B. It features the highest precision, lowest noise, and lowest distortion at the highest update rate.

DAC11001B can be fit for numerous applications with the benefit of both static and dynamic performance. However, this application note reviews three leading applications that would benefit from the outstanding AC performance of this new DAC.

Also, it showcases how DAC11001B improves overall system-level performance.

2 Key Applications

Audio testers, high-performance audio, and automated test equipment are vital applications where high resolution, precision, and speed are critical specifications.

2.1 Audio Tester

Audio testers needs to generate high-fidelity tones covering audio ranges (20 Hz to 20 kHz) and extend to hundreds of kilohertz. Typically, test stimuli are sine tones, and their purity is defined by total harmonic distortion (THD) and signal to noise ratio (SNR).

Audio testing systems are built with a high-performance audio DAC or precision DAC to generate a high-fidelity pure sine tones for testing. The resolution of these DACs ranges from 16 - 20 bits, with low noise and very low glitch energy.

Currently, designers use delta-sigma DAC topologies to generate audio signals, which produce out-of-band noise requiring additional digital signal processing logic and noise shaping filter. The additional digital signal processing adds extra information for correctness that is not present in the original signal. Also, it increases the overall system solution size and cost.

2.2 High Performance Audio

The most high-performance audio applications in the market are designed with delta-sigma DAC as compared to multiplying DAC or R-2R ladder network DACs with 16 to 18-bit resolution.

As discussed earlier, the delta sigma DAC had the benefit of improving the dynamic performance of the audio DACs, which were being limited by the achievable precision of the R-2R designs.

However, delta-sigma designs introduce noise on the output due to their high-frequency switching called “out-of-band noise”. This noise is generally out of the audible range but does result in the need for output filtering.

The DAC11001B features a flat noise density, which means that the out-of-band noise is much lower than a delta-sigma DAC. In addition, its advanced track-and-hold features result in a low output glitch which is input code independent.

This new technology allows designers to challenge the assumption that precision DACs are inadequate in high-fidelity audio applications.

2.3 Automated Test Equipment (ATE) and Arbitrary Waveform Generation (AWG)

Semiconductor ATEs, are specifically designed to test a wide range of electronic devices such as diodes, FETs, and integrated circuits like linear and mixed-signal devices. Testing is performed out by sending a stimulus signal to device under test (DUT) and capturing response from DUT. The stimulus can be either static or dynamic based on testing to be performed.

Most of these testers demand their driver circuits to be capable of generating a stimulus signal with a 16-, 18-, or 20-bit resolution, less than one ppm level of DC accuracy, ultra-low noise with wide bandwidth, and a fast update rate to test today's advanced devices.

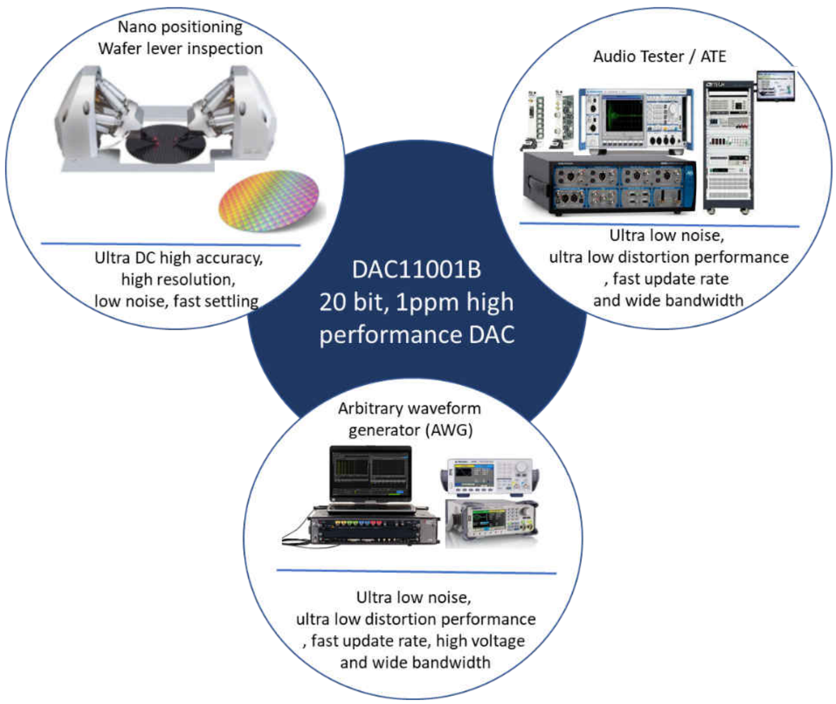

Figure 2-1. DAC11001B Target End Applications

3 DAC11001B

DAC11001B features a 20-bit resolution, highly accurate INL, DNL (1ppm max), ultra-low noise performance (7nV/√Hz) with fast settling time (1 µs), and an on-chip enhanced deglitch circuit that enables very low glitch (1nV-s), which helps to generate a 1-kHz ultra-low distortion waveform with a THD of -120dB. The DAC11001B device incorporates a power-on reset (POR) circuit so that the DAC powers on with known values in the registers. With external references, the DAC output ranges from positive reference (VREFPF) to the negative reference (VREFNF) can be achieved, including asymmetric output ranges. The DAC11001B uses a versatile 4–wire serial interface that operates at clock rates of up to 50 MHz.

System design needs careful attention to select companion parts, both active and passive components in order to achieve the 20-bit, ultra-low noise distortion performance guaranteed by the DAC11001B in the real world. Thermal effect seriously affects system performance, so components with low-temperature coefficients must be used, and all inherent component errors and generated errors from the signal chain must be low or comparable to the DAC-generated errors.

For more details on error sources and calculations, see *Error Calculation for Unbuffered R2R DAC – Example Using DAC11001A*.

In addition, the PCB layout also plays a vital role in reducing errors in the system. The analog and digital components must be isolated in the design, placing analog circuits away from high-frequency components such as switching power supplies and digital communications lines.

Figure 3-1 shows a typical signal chain with recommended parts to achieve the best AC performance.

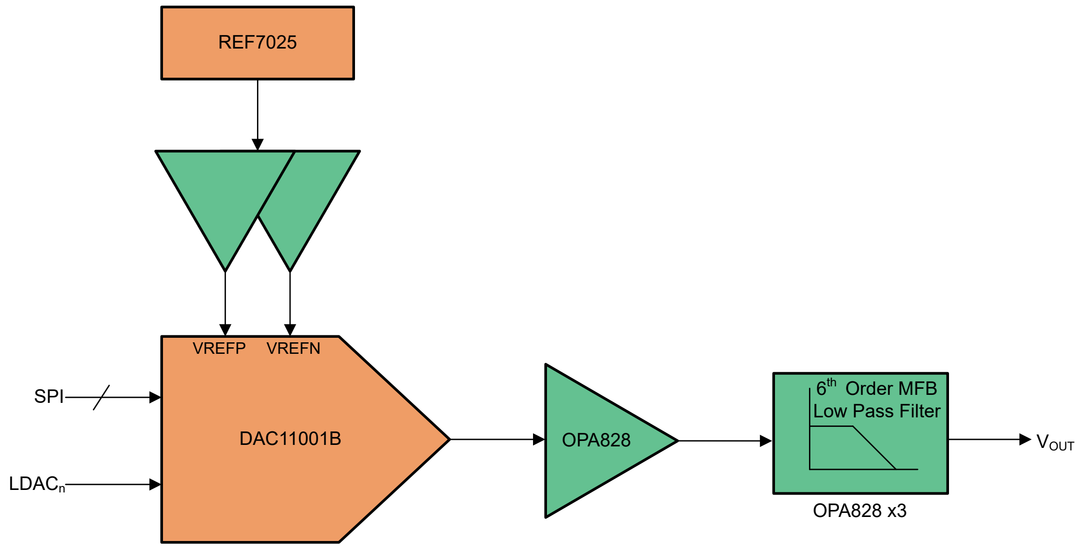

Figure 3-1. DAC11001B Signal Chain Block Diagram With Companion Parts

The DAC11001B offer an unbuffered voltage output to provide flexibility to customers to choose an external buffer based on their system performance.

In this circuit, the OPA828, a JFET operational amplifier (op amp), is used as a buffer at the output of the DAC11001B. The OPA828 offers a low-offset voltage (50 µV) and low noise (4 nV/√Hz typical), which is flat across the frequency band up to 100 kHz. The AC characteristics, including a 45-MHz gain bandwidth product (GBW), a slew rate of 150 V/µs, and precision DC characteristics, make the OPA828 an excellent choice for waveform generation applications. The OPA828 is also used to build an active filter to remove higher-order harmonics content.

The OPA827 is used as a reference buffer to drive the unbuffered reference input of the DAC11001B. The excellent DC performance of this device provides very low noise (4 nV at 1 kHz), very low drift (0.5 µV/°C, typical), and low-bias current (3 pA, typical). Also, the device supports a wide supply- voltage range, ±4 V to ±18 V, which supports the wide input reference requirement of the DAC11001B (up to ±15 V).

The signal chain uses REF7025 as a reference source that offers high precision, low noise, and a very low-temperature drift coefficient (2 ppm/°C) with high accuracy (±0.025%).

4 Performance Test Result

This document compares performance data taken on the DAC11001B with data for similar devices available in the market. The total harmonic distortion (THD) and total harmonic distortion, plus noise (THD+N), evaluates high-fidelity tones. The APx555B high-performance audio analyzer used to measure signal chain performance.

Table 4-1 and Figure 4-1 compare the spectrum performance of the DAC11001B and a competitor part while generating a 1 kHz sine tone with a 10 kSPS update rate and 9 Vpp amplitude.

The DAC11001B signals chain provides -115dB THD and -105 dB THD+N performance, which is almost a 20 dB improvement in the distortion over the competitor's performance.

Table 4-1. Distortion Performance at 1 kHz DAC Output

Device	Frequency	THD	THD+N
DAC11001B	1 kHz	-115 dB	-105 dB
COMPETITOR	1 kHz	-96 dB	-95 dB

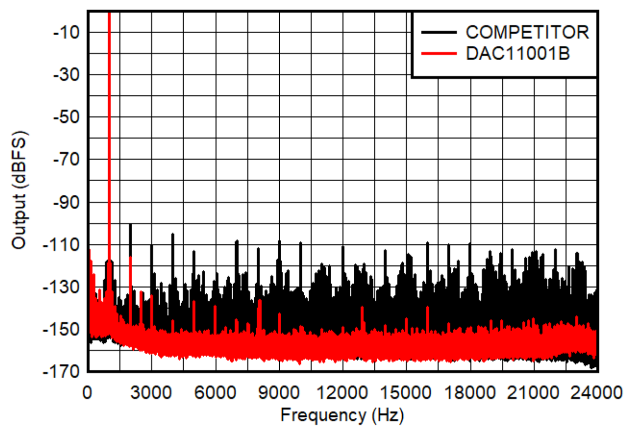

Figure 4-1. Spectrum DAC11001B vs Competitor – 1 kHz, 10 kSPS Update Rate, 9Vpp

Table 4-2. Test Condition

Parameter	Value
Pattern	Sine
Output voltage	9 Vp-p
DAC output signal frequency	1 kHz to 20kHz
DAC update rate	768 kSPS
SPI, SCLK frequency	38.4 MHz
Reference voltage	±4.5 V

Figure 4-2 and Figure 4-3 show the THD and THD+N performance of the DAC11001B and competitor part across frequency (1 kHz to 20 kHz) at 768 kSPS update rate.

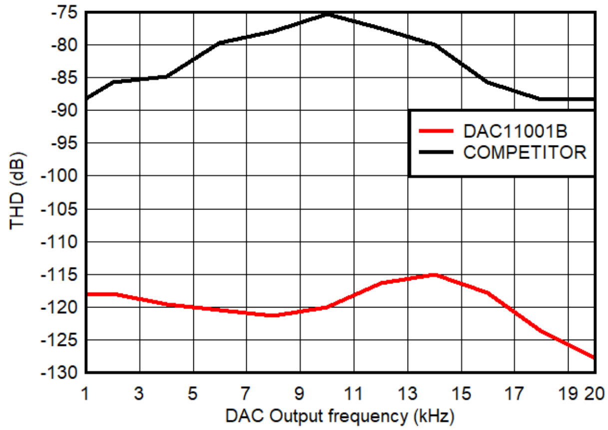

Figure 4-2. THD Performance

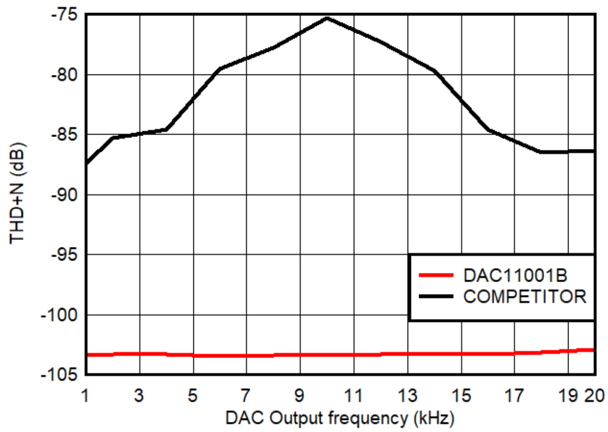

Figure 4-3. THD+N Performance

5 Competitor Analysis - Audio Tester Applications

Table 5-1 compares the DAC11001B performance with a few audio testers available in the market. The results show that the THD of the DAC11001B outperforms the competitors and other equipment existing in the market, and it is comparable to THD+N performance with Keysight U8900B.

Table 5-1. DAC11001B EVM vs Audio testers

End Equipments	THD	THD+N
DAC11001B EVM	-120	-106
COMPETITOR EVM	-88	-87
KEYSIGHT, U8903B Performance Audio Spectrum Analyzer	-116	-110
NI, NI4461 Sound and Vibration Module	-97	-97
R&S, UPP Audio Analyzer	-	-100

6 Summary

In summary, this application note encourages circuit designers and system developers to understand the true AC performance of the DAC11001B and how to build ultra-low noise, ultra-low distortion, and high-fidelity waveform generation for test and measurement applications like a high-performance audio tester, high-performance audio, arbitrary waveform generator, and automatic test equipment.

The competitor analysis helps designers to consider TI's DAC11001B, the industry's best 20-bit, high-precision DAC, for their systems to meet the current and future application demands.

7 References

- Texas Instruments: *Error Calculation for Unbuffered R2R DAC – Example Using DAC11001A*
- TI Precision Labs- Key AC & DC Specifications training

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