

TLV320ADCx140, TLV320ADCx120, PCMx120-Q1, PCMx140-Q1 Integrated Analog Anti-Aliasing Filter and Flexible Digital Filter



Diljith Thodi, Tanmay Halder

ABSTRACT

Analog anti-aliasing filters attenuate out-of-band high-frequency components prior to analog-to-digital converters (ADC). These filters prevent high frequencies from aliasing or folding back into the band of interest and degrading the performance of the ADC. The TLV320ADCx140/PCMx140-Q1 family of audio ADCs (TLV320ADC3140, TLV320ADC5140, TLV320ADC6140, PCM3140-Q1, PCM5140-Q1, PCM6140-Q1) as well as TLV320ADCx120/PCMx120-Q1 (TLV320ADC3120, TLV320ADC5120, TLV320ADC6120, PCM3120-Q1, PCM5120-Q1, PCM6120-Q1) have a built-in anti-alias filter, so no external anti-alias filter is needed. This application note describes the included anti-alias filter in the analog-to-digital conversion process in TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices.

Table of Contents

| | |
|--|---|
| 1 Introduction | 2 |
| 2 Inherent Anti-Aliasing in TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 | 2 |
| 3 Flexible Digital Filters | 4 |
| 3.1 Multi-Stage Decimation Filters..... | 4 |
| 3.2 Programmable Biquad Filters..... | 6 |
| 4 References | 7 |
| 5 Revision History | 7 |

List of Figures

| | |
|---|---|
| Figure 1-1. Folding Back of Noise and Interferer Due to Sampling..... | 2 |
| Figure 2-1. Block Diagram of Audio Signal Chain..... | 2 |
| Figure 2-2. Signal Transfer Function of ADC Modulator..... | 3 |
| Figure 2-3. Maximum Supported Signal Amplitude..... | 3 |
| Figure 3-1. Linear Phase Decimation Filter Response..... | 4 |
| Figure 3-2. Low-Latency Decimation Filter Response..... | 5 |
| Figure 3-3. Phase Deviation of Low-Latency Decimation Filter..... | 5 |
| Figure 3-4. Ultra-Low-Latency Decimation Filter Response..... | 6 |
| Figure 3-5. Ultra-Low-Latency Decimation Filter Phase Deviation..... | 6 |

List of Tables

| | |
|---|---|
| Table 3-1. Decimation Filter Characteristics..... | 4 |
|---|---|

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The process of converting analog signal to digital signal involves two steps: sampling the input analog signal and quantization of the sampled signal to a digital value. Sampling converts the continuous-time signal to discrete-time samples spaced by the sampling frequency whereas quantization digitizes the sampled signal to a discrete amplitude value. Theoretically, the Sampling Theorem dictates that the sampling frequency (F_S) can be chosen at least twice as high as the maximum input signal frequency content (F_B). However, any out-of-band signal, interference, or noise from $N \times F_S \pm F_B$ ($N = 1, 2, 3$, and so forth) is folded back into the desired band, overlapping it with the input signal. Figure 1-1 depicts this folding of the out-of-band frequencies greater than F_S into the in-band frequency (F_B). To limit the interference of these out-of-band frequencies with the in-band frequencies, a low-pass filter is used, which greatly reduces the out-of-band frequencies before the input of the analog-to-digital converter (ADC). By selecting large order low pass filters, the aliasing components are greatly attenuated, but higher order filters come at higher cost.

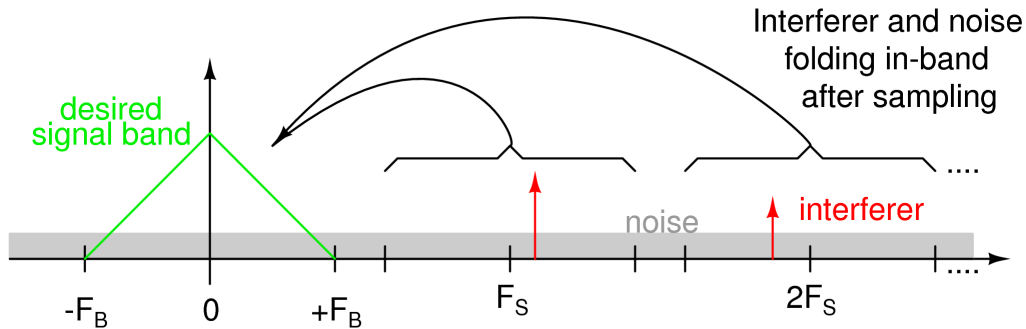


Figure 1-1. Folding Back of Noise and Interferer Due to Sampling

2 Inherent Anti-Aliasing in TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1

TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices use a delta-sigma, analog-to-digital converter to digitize the input signal. The ADC employs over-sampling combined with noise shaping to achieve high performance. Figure 2-1 shows the simplified block diagram of the audio signal chain.

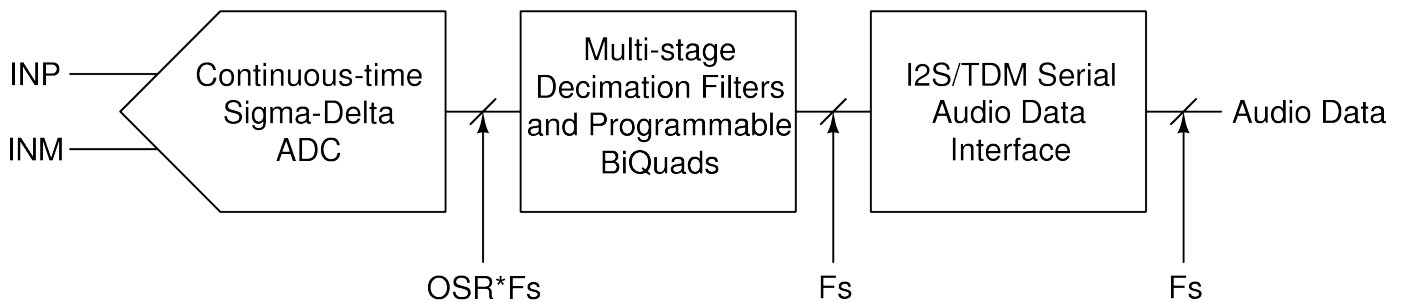


Figure 2-1. Block Diagram of Audio Signal Chain

To improve the performance of the conversion, TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 not only over-samples the signal to simplify the design of the anti-alias filter, but also adds notches in the signal transfer function at multiples of the modulator frequency (F_{MOD}). The ratio between the sample rate of the modulator and the output sample rate is called the over-sampling ratio (OSR). The frequency bands that can potentially fold into in-band and corrupt the signal of interest are around $N \times F_{MOD} \pm 20$ kHz ($N = 1, 2, 3$, and so forth). The notches in the modulator transfer function heavily attenuates (> 100 dB) these frequency bands. Figure 2-2 shows the signal transfer function of the modulator. The sample frequency of the modulator is set to 6.144 MHz for all multiples and sub-multiples of 48 kHz. The 44.1 kHz family of sample rates use a modulator sample frequency of 5.644 MHz. The integrated digital filters, present down the signal chain, cut off the out-of-band frequency noise at every stage of decimation, providing stop band attenuation of more than 70 dB. The overall architecture helps reduce the system cost and overall solution size by getting rid of the on-board

operational amplifiers and passives that are required in building a complex high order external analog anti-alias filter.

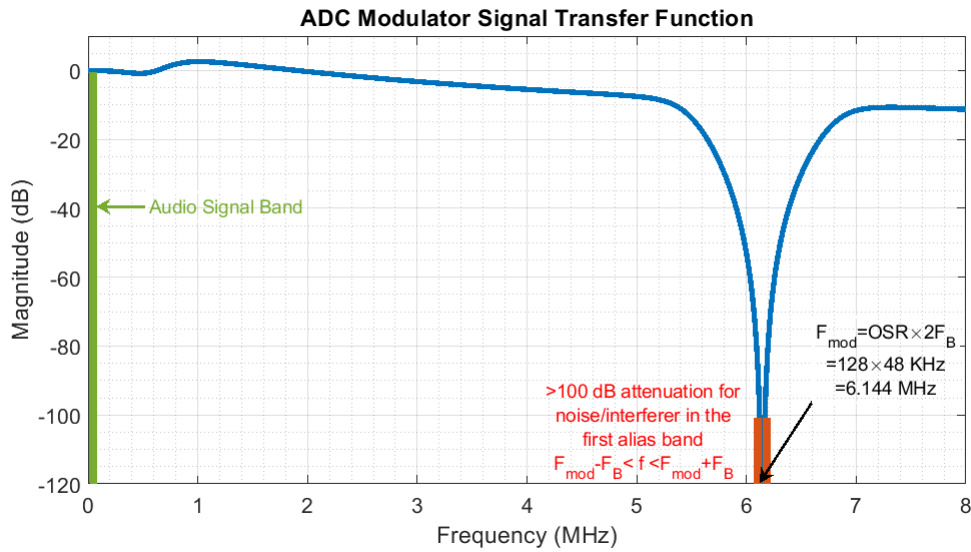


Figure 2-2. Signal Transfer Function of ADC Modulator

The signal chain in the TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices is tolerant to noise/interferer at the input (no anti-alias required, generally). However, the signal chain cannot sustain noise/interferer above a certain limit. With full scale signal present, the maximum supported integrated noise at the input (entire band) is 0.0075 V (-48 dB at 2 Vrms). In the absence of signal, the supported value is 0.01 V (-46 dB at 2 Vrms) of integrated noise. Note that it is assumed that this input noise has a shaped spectrum equivalent to a second order high pass transfer function. For tones (interferer/signal) at specific frequencies, Figure 2-3 shows that the amplitude of the tone can be supported at various frequencies without saturating the modulator.

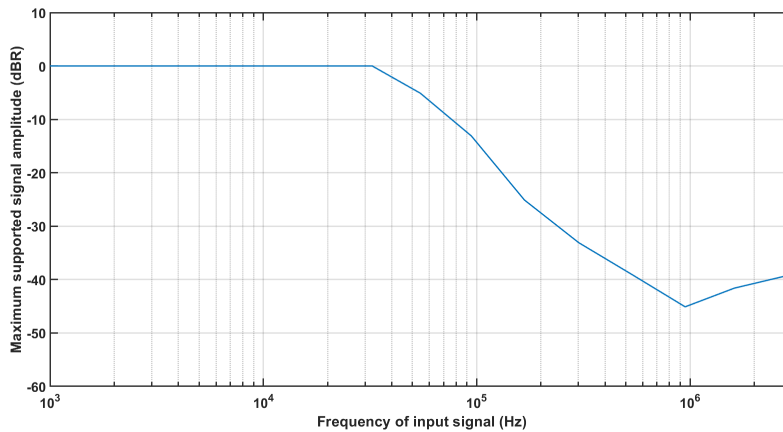


Figure 2-3. Maximum Supported Signal Amplitude

If high out-of-band interferer/noise is present, it is recommended it use a first order or second order anti-alias filter with cut off at 20 kHz to keep the out-of-band noise/interferer in check and prevent the signal chain from saturating.

3 Flexible Digital Filters

Once the analog signal is sampled into a discrete signal by the ADC, decimation filters attenuate out-of-band noise. In addition to decimation filters, programmable digital bi-quad filters can further shape the in-band signal frequency response. The following sections describe the decimation filters and bi-quad filter options offered by TLV320ADCx140 /TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices.

3.1 Multi-Stage Decimation Filters

TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices offer three distinct sets of decimation filters: Linear Phase, Low-Latency, and Ultra-Low-Latency. [Table 3-1](#) shows the comparative performance of the three decimation filter options. The linear phase filters provide zero group delay deviation. The low-latency and ultra-low-latency filters offer lower group delay and higher attenuation but with higher group delay deviation than the linear phase filters. Refer to *Linear Phase Filters*, *Low-Latency Filters*, and *Ultra-Low-Latency Filters* sections of the [TLV320ADC5140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC Data Sheet](#), [TLV320ADC6140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC Data Sheet](#), and [TLV320ADC3140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC Data Sheet](#) for exact filter responses for supported sample rates.

Table 3-1. Decimation Filter Characteristics

| | LINEAR PHASE | LOW LATENCY | ULTRA-LOW LATENCY |
|--|--------------|-------------|-------------------|
| GROUP DELAY (IN NUMBER OF SAMPLES) | 10–20 | 5–7 | 3–5 |
| GROUP DELAY DEVIATION (IN NUMBER OF SAMPLES) | 0 | < 0.1 | < 0.5 |
| OUT-OF-BAND ATTENUATION (dB) | > 72 | > 85 | > 85 |

3.1.1 Linear Phase

Linear phase decimation filters have zero group delay deviation across frequency. The latency of these filters are in the order of around 10–20 samples at the output sample rate. The out-of-band attenuation is around 72 dB for the linear phase filters, across all sample rates. [Figure 3-1](#) shows the linear phase response for 48-kHz sample rates. The dashed line indicates the minimum out-of-band attenuation level, which is around 74 dB. This implies that the strength of any aliased out-of-band noise component would be attenuated by at least 74 dB by the decimation filter chain. Linear phase filters delay all frequency components by the same amount and consequently do not cause any phase distortion. These filters are recommended for applications requiring where time domain waveform fidelity is paramount, like professional audio recording.

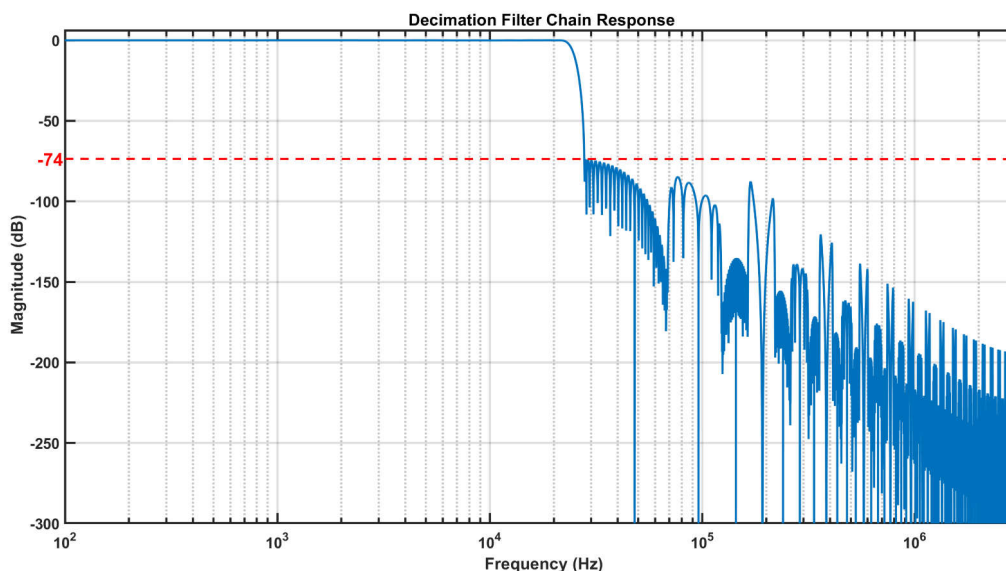


Figure 3-1. Linear Phase Decimation Filter Response

3.1.2 Low-Latency Filters

Low-latency decimation filters have smaller group delay (around 5–7 samples at the output sample rate) than the linear phase filters but have non-zero group delay deviation. The group delay deviation is typically less than one-hundredth the time period of the output sampling rate. The out-of-band attenuation is greater than 85 dB for low-latency filters across all sample rates. Figure 3-2 shows the low-latency response for the 48-kHz sample rates for reference. The dashed line indicates the minimum out-of-band attenuation level, which is around 86 dB. This implies that the strength of any aliased out-of-band noise component would be attenuated by at least 86 dB by the low-latency decimation filter chain. Low-latency filters are suitable for applications requiring fast analog-to-digital conversion and process the low- and mid-frequency bands. Figure 3-3 shows the phase deviation plot of the 48 kHz low-latency filter. It has a near-zero (less than 0.3 degrees and greater than -0.25 degrees) phase deviation from DC to $0.37 \times f_s$ Hz. Applications that has a band of interest is less than $0.37 \times f_s$ Hz can use the low-latency filters and take advantage of the faster conversion.

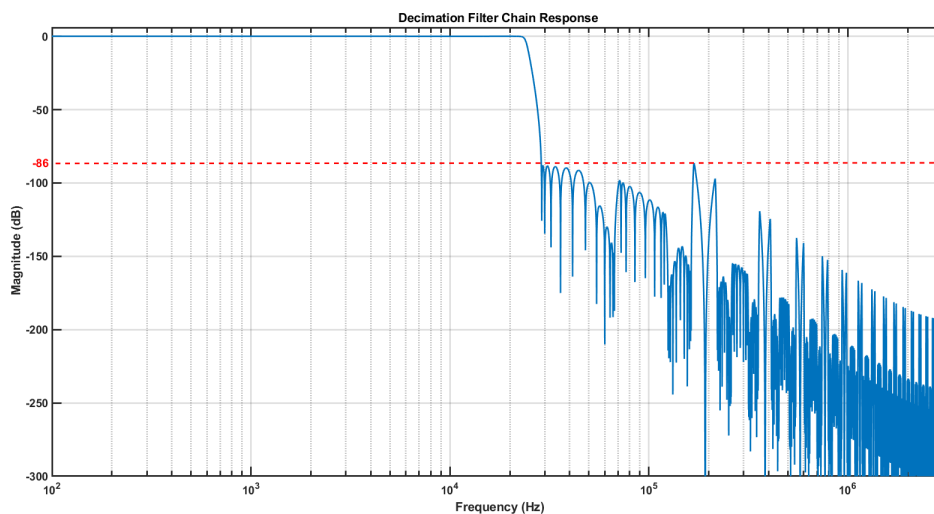


Figure 3-2. Low-Latency Decimation Filter Response

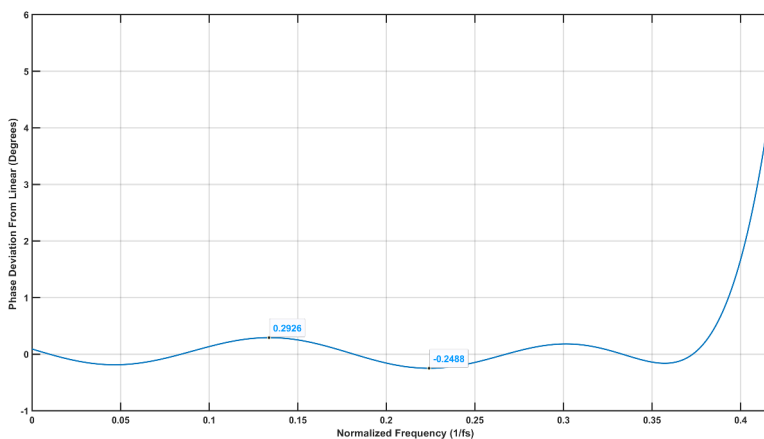


Figure 3-3. Phase Deviation of Low-Latency Decimation Filter

3.1.3 Ultra-Low-Latency Filters

Ultra-low-latency decimation filters have the smallest group delay (around 3–4 samples at output sample rate) but have larger group delay deviations than low-latency filters. The out-of-band attenuation is greater than 85 dB for ultra-low-latency filters. Figure 3-4 shows the ultra-low-latency frequency response for the 48-kHz sample rate. The magnitude response for the ultra-low-latency filters are nearly identical to the low-latency filters. Ultra-

low-latency filters having lower group delay but higher phase deviation. Figure 3-5 shows the phase deviation of the 48 kHz sample rate filter. The phase deviation is not very large (less than 14.5 degrees and greater than -10.3 degrees) for frequencies less than $0.3 \times f_s$. Ultra-low-latency filters are suitable for applications that require extremely fast conversion but can tolerate small amounts of phase deviation.

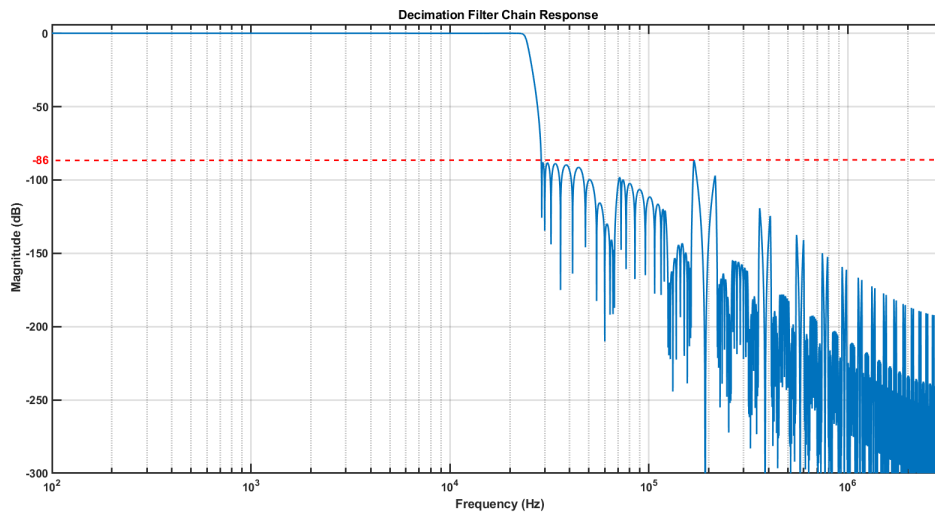


Figure 3-4. Ultra-Low-Latency Decimation Filter Response

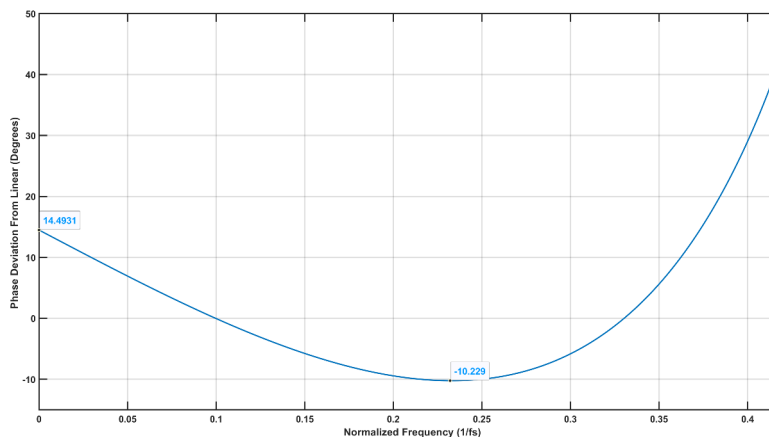


Figure 3-5. Ultra-Low-Latency Decimation Filter Phase Deviation

3.2 Programmable Biquad Filters

In addition to the multi-stage decimation filters for out-of-band attenuation, the TLV320ADCx140/TLV320ADCx120/PCMx120-Q1/PCMx140-Q1 devices also support digital bi-quad filters for in-band frequency shaping. For example, in noise cancellation or equalization, the signal band of interest is usually less than a few 100 Hz. Using programmable digital bi-quad filters, the filter parameters can be configured to suppress undesirable audio signals prior to any digital processing. These filters can be used as low-pass, high-pass, band-pass, or band-reject filters. For additional information on bi-quad filter configuration, refer to the [TLV320ADCx140 Programmable Bi-quad Filter Configuration and Applications](#), application note.

4 References

- Texas Instruments, [TLV320ADC5140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC](#), data sheet.
- Texas Instruments, [TLV320ADC3140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC](#), data sheet.
- Texas Instruments, [TLV320ADC6140 Quad-Channel, 768-kHz, Burr-Brown Audio ADC](#), data sheet.
- Texas Instruments, [TLV320ADC3120 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [TLV320ADC5120 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [TLV320ADC6120 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [PCM6120-Q1 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [PCM5120-Q1 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [PCM3120-Q1 2-Channel, 768-kHz, Burr-Brown™ Audio ADC](#), data sheet.
- Texas Instruments, [PCM6140-Q1 Quad-Channel, 768-kHz, Burr-Brown™ Audio ADC data sheet](#), data sheet.
- Texas Instruments, [PCM5140-Q1 Quad-Channel, 768-kHz, Burr-Brown™ Audio ADC data sheet](#), data sheet.
- Texas Instruments, [PCM3140-Q1 Quad-Channel, 768-kHz, Burr-Brown™ Audio ADC data sheet](#), data sheet.

5 Revision History

Changes from Revision A (April 2022) to Revision B (January 2024) **Page**

- Added *PCMx140-Q1* throughout the document..... 1
-

Changes from Revision * (December 2019) to Revision A (April 2022) **Page**

- Added *TLV320ADCx120/PCMx120-Q1* throughout the document..... 1
 - Updated the numbering format for tables, figures, and cross-references throughout the document..... 1
-

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](https://www.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 © 2024, Texas Instruments Incorporated