Application Report
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PCM6xx0 Integrated Analog Anti-Aliasing Filter and Flexible Digital Filter

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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 PCM6xx0-Q1 family of automotive audio ADCs (PCM6240-Q1, PCM6260-Q1, PCM6340-Q1, PCM6360-Q1, and PCM6480-Q1) has a built-in anti-alias filter, so no external anti-alias filter is needed. This application report describes the included anti-alias filter in the analog-to-digital conversion process in PCM6xx0-Q1 devices.

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Trademarks

1 Introduction

The process of converting an analog signal to a digital signal involves two steps: sampling the input analog signal and quantizing 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, Nyquist Sampling Theorem dictates that the sampling frequency (FS) must be greater than twice as high as the maximum input signal frequency content (FB). However, any out-of-band signal, interference, or noise from N × FS ± FB (N = 1, 2, 3, and so forth) is folded back into the desired band, overlapping it with the input signal. Figure 1 depicts this folding of the out-of-band frequencies greater than FS into the in-band frequency (FB). To limit the interference of these out-of-band frequencies with the in-band frequencies, a low-pass filter is used, which greatly attenuates 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.

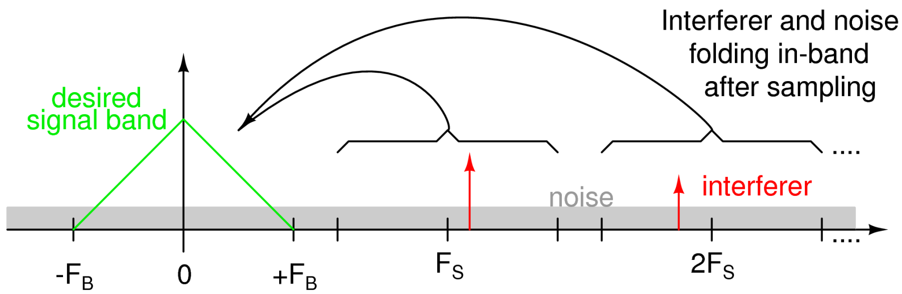

Figure 1. Folding Back of Noise and Interferer Due to Sampling

2 Inherent Anti-Aliasing in PCM6xx0-Q1

PCM6xx0-Q1 devices use a delta-sigma, analog-to-digital converter to digitize the input signal. The ADC employs oversampling combined with noise shaping to achieve high performance. Figure 2 shows the block diagram of the audio signal chain.

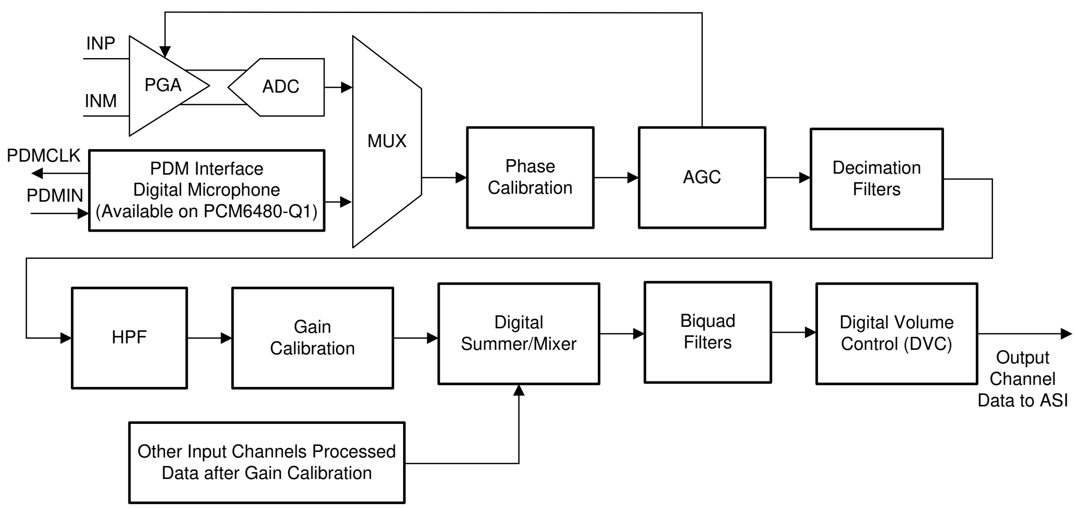

Figure 2. Block Diagram of Audio Signal Chain

A continuous-time delta-sigma architecture is used for the ADCs in PCM6xx0-Q1 devices. The sampling frequency of the ADC modulator is referred to as the modulator frequency (F_{MOD}). To improve the performance of the conversion, the PCM6xx0-Q1 device not only oversamples 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 × F_{MOD} ±20 kHz (N = 1, 2, 3, and so forth). The notches in the modulator transfer function heavily attenuates (> 100 dB) these frequency bands. Figure 3 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 in 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.

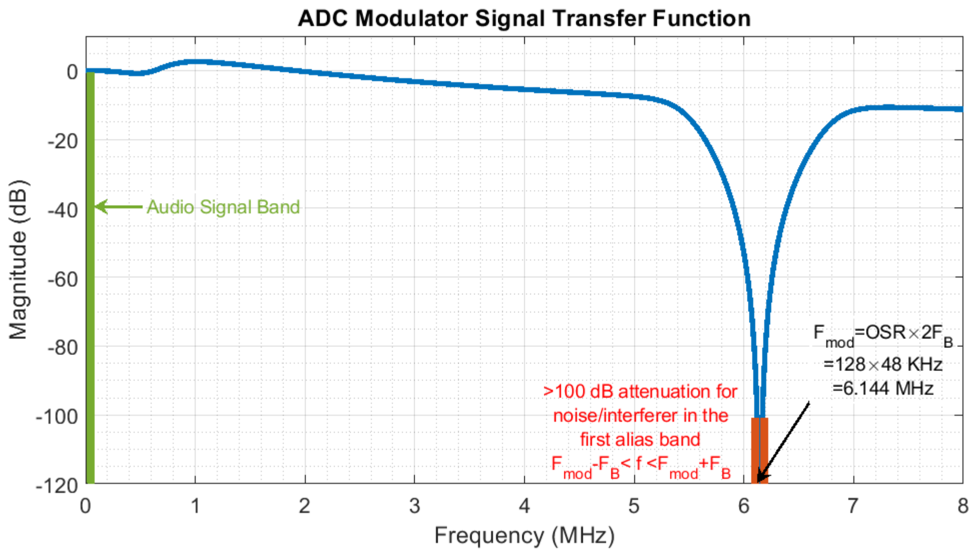

Figure 3. Signal Transfer Function of ADC Modulator

The signal chain in the PCM6xx0-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. To meet data sheet parameters for ADC performance, the PCM6xx0-Q1 analog input must not exceed the amplitude envelope shown in Figure 4. With full scale signal present, the maximum supported integrated noise at the input (entire band) is 0.0075 V (–48 dBr at 2 V_{RMS}). In the absence of a signal, the supported value is 0.01 V (–46 dBr at 2 V_{RMS}) 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.

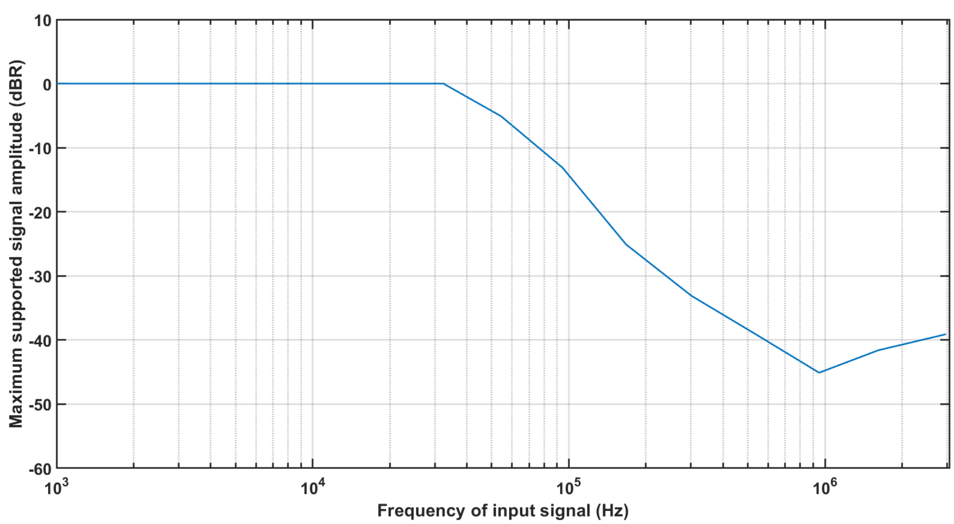

Figure 4. Maximum Supported Signal Amplitude

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 reduce out-of-band noise/interference to levels below the limits to 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 PCM6xx0-Q1 devices.

3.1 Multistage Decimation Filters

The PCM6xx0-Q1 devices offer three distinct sets of decimation filters: Linear Phase, Low-Latency, and Ultra-Low-Latency. Table 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. See the *Linear Phase Filters*, *Low-Latency Filters*, and *Ultra-Low-Latency Filters* sections of *PCM6xx0-Q1 Automotive, 4-Channel and 6-Channel, 768-kHz, Audio ADC With Integrated Microphone Bias and Input Fault Diagnostics Data Sheet* for exact filter responses for supported sample rates.

Table 1. Decimation Filter Characteristics

	LINEAR PHASE	LOW LATENCY	ULTRA-LOW LATENCY
Group Delay (in Number of Samples at FS)	10–20	5–7	3–5
Group Delay Deviation (in Number of Samples at FS)	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 greater than 72 dB for linear phase filters across all sample rates. Figure 5 shows the linear phase response for 48-kHz sample rate which has a stop-band attenuation specification of 74 dB. The dashed line indicates the minimum out-of-band attenuation level (approximately 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.

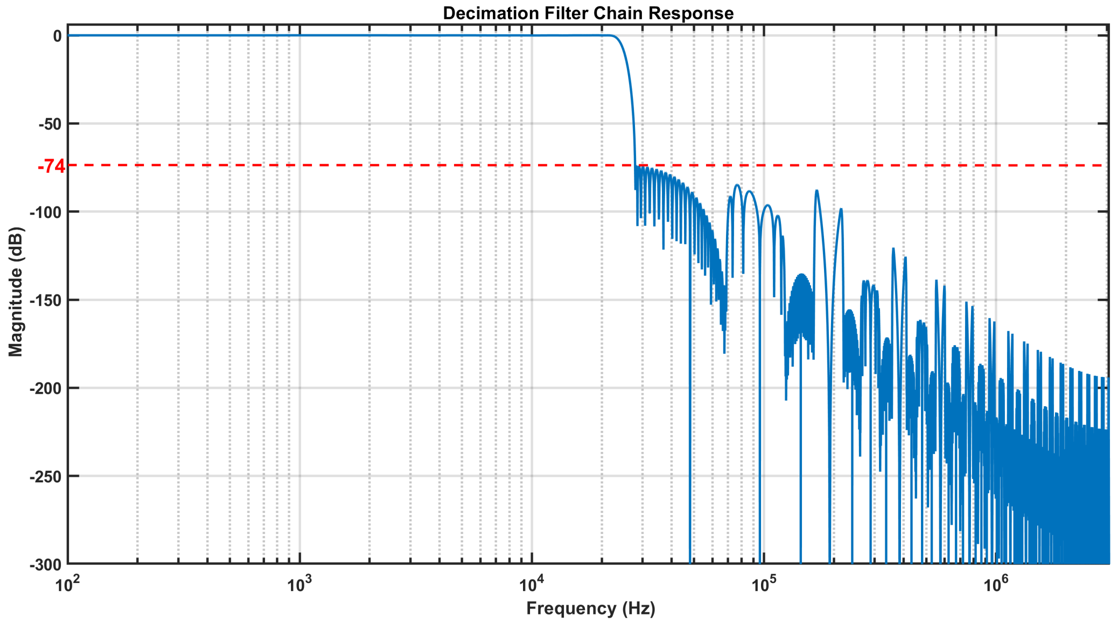

Figure 5. Linear Phase Decimation Filter Response

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 6 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 7 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 × fs Hz. Applications that have a band of interest that is less than 0.37 × fs Hz can use the low-latency filters and take advantage of the faster conversion.

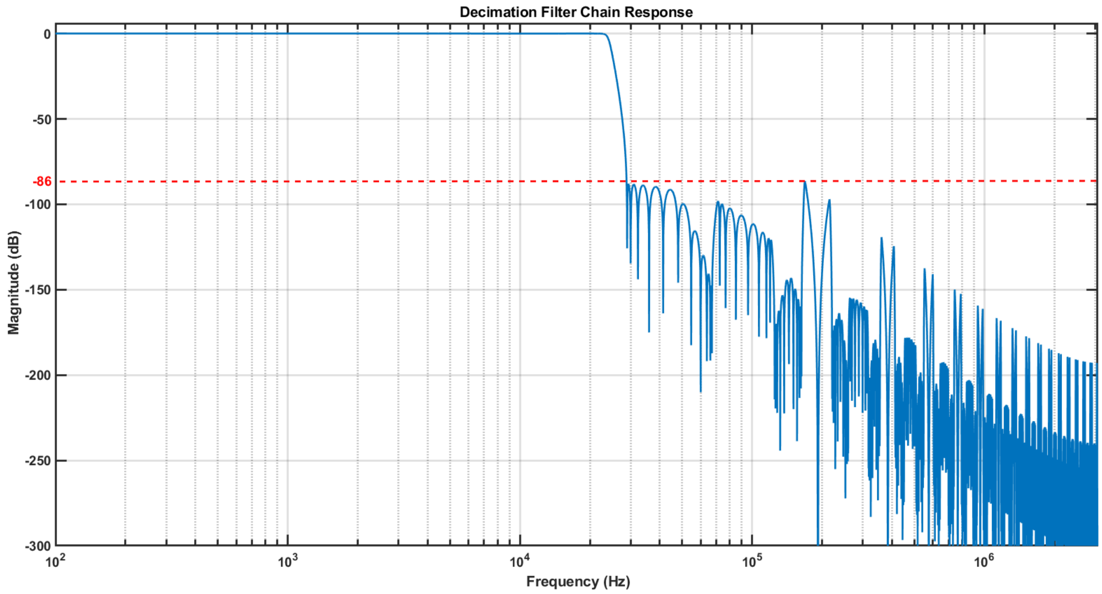

Figure 6. Low-Latency Decimation Filter Response

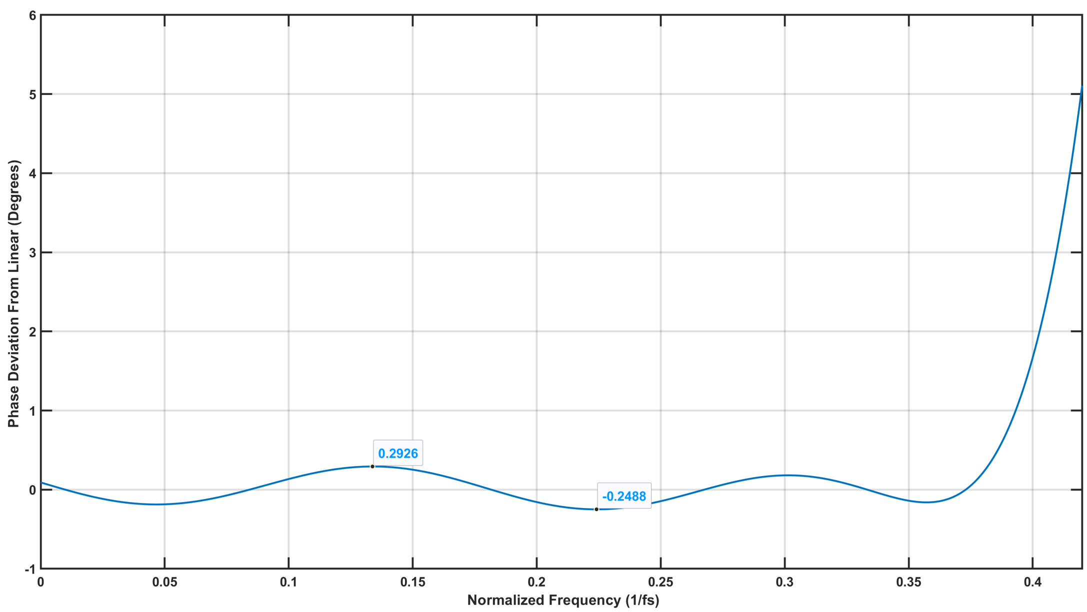

Figure 7. Phase Deviation of Low-Latency Decimation Filter

3.1.3 Ultra-Low-Latency Filters

Ultra-low-latency decimation filters have the smallest group delay (around 3–4 samples at the 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 8 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, but the ultra-low-latency filters having lower group delay and higher phase deviation. Figure 9 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 × fs. Ultra-low-latency filters are suitable for applications that require extremely fast conversion but can tolerate small amounts of phase deviation.

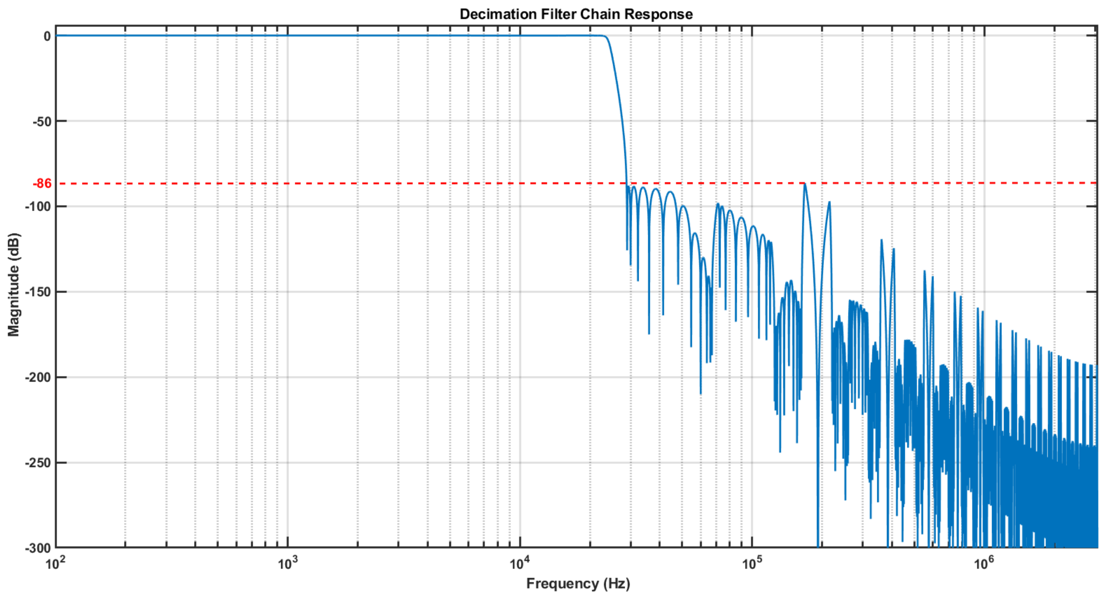

Figure 8. Ultra-Low-Latency Decimation Filter Response

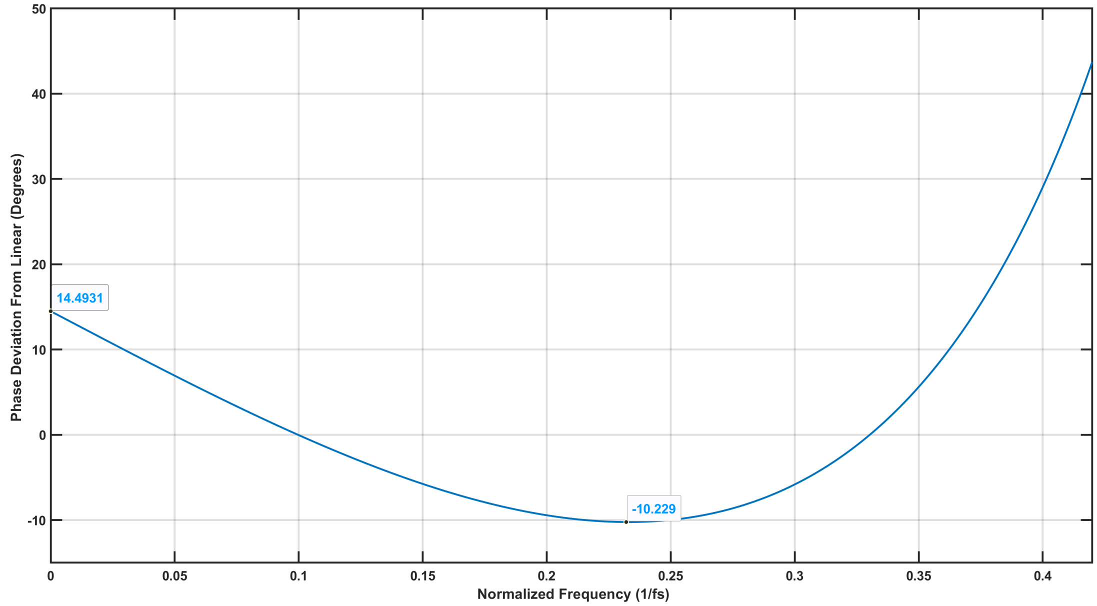

Figure 9. Ultra-Low-Latency Decimation Filter Phase Deviation

3.2 Programmable Bi-quad Filters

In addition to the multi-stage decimation filters for out-of-band attenuation, the PCM6xx0 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, see the *PCM6xx0-Q1 Programmable Bi-quad Filter Configuration and Applications Application Report*.

4 References

- Texas Instruments, *PCM6xx0-Q1 Automotive, 4-Channel and 6-Channel, 768-kHz, Audio ADC With Integrated Microphone Bias and Input Fault Diagnostics*
- Texas Instruments, *PCM6xx0-Q1 Sampling Rates and Programmable Processing Blocks Supported*

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