Application Note

Increasing the Dynamic Range and SNR of Audio ADC With Channel Summation

TEXAS INSTRUMENTS

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ABSTRACT

In this application note, channel summation, a simple but powerful method to increase the dynamic range and SNR of audio ADCs is discussed. This application note demonstrates how the dynamic performance of ADC increase by a factor of 3 dB for every doubling of the number of converters used in parallel.

The channel-summation feature is available in TLV320ADC6140, TLV320ADC5140, TLV320ADC3140, TLV320ADC6120, TLV320ADC5120 and TLV320ADC3120 audio ADCs. Practical results from TLV320ADC6140 are obtained and used to demonstrate this channel summation method in-depth.

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1 Introduction

In the audio world, a common technique to increase the dynamic range of a system is to connect two, four or more ADCs in parallel with inputs tied together. This method uses the principle that correlated signals add on linearly whereas uncorrelated signals, such as noise sources, add on as root-sum-square. When using two ADCs, this results in a signal-to-noise ratio (SNR) magnitude increase by 1.414 or 3 dB for two equal amplitudes. In this application note, this technique is discussed in more detail and the equations that yield the improvement are derived.

2 SNR Enhancement by Summation of ADCs

In audio ADCs, oversampling decreases quantization noise in the band of interest, which results in improved SNR. The theoretical value of signal-to-noise ratio of an N-bit ADC can be expressed as

$$\mathrm{SNR} = 6.02\mathrm{N} + 1.76\ \mathrm{dB} \tag{1}$$

Where N is the number of bits. By oversampling, the SNR can be increased and a designer can quantify the improvement of SNR by using the following equation

$$\mathrm{SNR_{OS}} = 6.02\mathrm{N} + 1.76\ \mathrm{dB} + 10 \times \log(\mathrm{OSR}) \tag{2}$$

where OSR (oversampling ratio) is the ratio of sampling frequency to twice the input frequency, which is also known as the Nyquist frequency. This ratio is given by

$$\mathrm{OSR} = \frac{\mathrm{fs}}{2 \times \mathrm{fin}} \tag{3}$$

The preceding equation shows that SNR improves by 3 dB per octave. So, if OSR = 2, then the SNR improves by 3 dB; if OSR = 4, the SNR improves by 6 dB.

The TLV320ADC5140 and TLV320ADC6140 devices from TI's Audio ADC portfolio features the Dynamic Range Enhancer (DRE) algorithm that can be used to improve the far-field recording performance by improving the dynamic range of the ADC channel at low signal levels. The DRE is a digitally-assisted algorithm that dynamically adjusts the front-end programmable gain amplifier (PGA) to improve the signal-to-noise ratio of low-level signals while preventing high-level signals from saturating the PGA and ADC.

The two methods described in earlier sections are embedded in the design of ADCs. There is another method to improve the dynamic range which is similar to the oversampling method. In this method, instead of oversampling, two or four or more ADCs are used in parallel. In this approach, the same input is fed to all ADCs, as the inputs are all tied together, the outputs are summed and averaged to yield an improved dynamic range. In Figure 2-1, two identical ADCs are connected at the input, receiving the same voltage. The outputs are summed in the digital domain and averaged using back-end digital processing within an FPGA or digital signal processor.

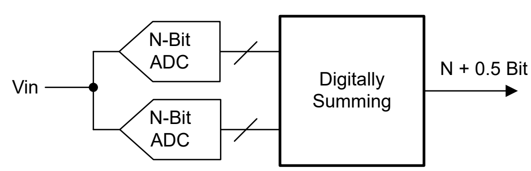

Figure 2-1. Connecting Two Identical ADCs and Summing ADC Outputs

Equation 1 through Equation 9 show how using this approach improves dynamic range. When two signals with the same frequency and phase are summed, the signals sum in terms of voltage. The result of this summation is

$$\mathrm{Vsum} = \mathrm{V1} + \mathrm{V2} \tag{4}$$

However, random signals, (such as noise, which have different frequencies and phases), sum in terms of power. Noise from two separate converters or channels are white and random, which means that the noise is predominantly uncorrelated from one channel or device to the other. Since noise signals are random, the signals must be treated by statistical means. The result for summation of two noise sources are

$$V_n^2 = V_{n1}^2 + V_{n2}^2 \quad (5)$$

Figure 2-1 shows a circuit with two identical ADCs. Two identical ADCs are used, the same input is applied to both ADCs, and the output of each is sent to be summed and averaged in the digital domain. The input of each ADC consists of the input signal as well as the noise. The two outputs can be summed using the following equation

$$Vout_{sum} = Vin1 + Vin2 + \sqrt{{V_{n1}}^2 + {V_{n2}}^2} \quad (6)$$

In the preceding equation, both inputs are identical. The summation of the these signals doubles the signal level which is equivalent to a 6-dB increase in signal level, whereas the summation of uncorrelated noise sources increases the noise level by a factor of 1.4 or 3 dB. Overall, there is a 3-dB improvement in dynamic range. This concept can be expanded to more parallel devices and SNR can be improved even more. For example, if four ADCs are used in parallel, the outcome is a 6-dB increase in SNR. Considering Equation 1, which calculates the SNR based on number of bits, the effective number of bits (ENOB) can be calculated using

$$ENOB = \frac{SNR - 1.76}{6.02} \quad (7)$$

With the 3-dB improvement of SNR, the new ENOB’ is calculated as

$$ENOB' = \frac{SNR' - 1.76}{6.02} \quad (8)$$

Where SNR’=SNR+3 for two converters used in parallel. Replacing SNR’ in Equation 8, results in the following equation.

$$ENOB' = \frac{SNR + 3 - 1.76}{6.02} = ENOB + 0.498 \quad (9)$$

For each doubling of the number of devices used in parallel, the effective number of bits increases by approximately 0.5, improving the SNR by 3 dB.

3 Alternative Method to Summation

Using two ADCs or channels within the same IC yields better results, since many parameters of the converters like gain, gain error, offset, and bandwidth are typically well-matched and do not introduce unwanted errors when the two signals are summed and averaged together. In theoretical conditions, when Vin = Vin1= Vin2, the resulting output is (Vin1+Vin2)/2 = Vin. However if there is a common error added to the input, it is passed along to the output. To avoid this situation, it is possible to invert one of the inputs to one ADC and instead of summation, a digital subtraction can be performed at the output. This method, in essence, is the same as the summation method with the additional advantage of canceling out any common error to both devices. Equation 10 mathematically expresses the two converters inputs of Vin1+e and Vin2+e.

$$Vout = \frac{(Vin1 + e) - (Vin2 + e)}{2} \quad (10)$$

But since Vin2 = -Vin1, Equation 11 can be expressed as the following equation to eliminate the common error (e).

$$Vout = \frac{Vin1 + Vin1}{2} \quad (11)$$

Either of the above methods can improve the SNR by 3 dB for every doubling of the number of converters used.

4 Practical Results

The TLV320ADC6140 from Texas Instruments is used to demonstrate the improvement of dynamic range and SNR for ADCs. The TLV320ADC6140 has an embedded channel summation mode to achieve higher SNR. This option can be activated for 2-channels or 4-channels using the assigned register (0x6B). For this demonstration, 4-channel summation mode is enabled, which mathematically performs the following operation: (CH1 + CH2 + CH3 + CH4) / 4. Table 4-5 through Table 4-8 show the performance improvement for the TLV320ADC6140 by summation of 2 and 4 channels.

In this mode, the digital recording data is averaged with equal weighing, which helps reduce the effective recorded noise.

Table 4-1. Improvement in Dynamic Range With 2-Channel Summation and DRE Enabled

Dynamic Range	Pre-Summation (dBFS)	Post-Summation (dBFS)	Improvement (dB)
Channel 1	123.25	126.54	3.29
Channel 2	123.25		
Channel 3	123.19	126.52	3.33
Channel 4	123.19		

Table 4-2. Improvement in Dynamic Range With 4-Channel Summation and DRE Enabled

Dynamic Range	Pre-Summation (dBFS)	Post-Summation (dBFS)	Improvement (dB)
Channel 1	123.25	129.52	6.3
Channel 2	123.25		
Channel 3	123.19		
Channel 4	123.19		

Table 4-3. Improvement in SNR With 2-Channel Summation and DRE Enabled

SNR	Pre-Summation (dBFS)	Post-Summation (dBFS)	Improvement (dB)
Channel 1	123.25	126.25	3.00
Channel 2	123.25		
Channel 3	123.19	126.13	2.94
Channel 4	123.19		

Table 4-4. Improvement in SNR With 4-Channel Summation and DRE Enabled

SNR	Pre-Summation (dBFS)	Post-Summation (dBFS)	Improvement (dB)
Channel 1	123.25	129.16	5.94
Channel 2	123.25		
Channel 3	123.19		
Channel 4	123.19		

Table 4-5. Improvement in Dynamic Range With 2-Channel Summation and DRE Disabled

Dynamic Range	Pre-Summation (dB)	Post-Summation (dB)	Improvement (dB)
Channel 1	113.25	116.13	2.88
Channel 2	113.25		
Channel 3	113.19	116.13	2.94
Channel 4	113.19		

Table 4-6. Improvement in Dynamic Range With 4-Channel Summation and DRE Disabled

Dynamic Range	Pre-Summation (dB)	Post-Summation (dB)	Improvement (dB)
Channel 1	113.25	118.73	5.51
Channel 2	113.25		
Channel 3	113.19		
Channel 4	113.19		

Table 4-7. Improvement in SNR With 2-Channel Summation and DRE Disabled

SNR	Pre-Summation (dB)	Post-Summation (dB)	Improvement (dB)
Channel 1	112.94	116.06	2.96
Channel 2	112.94		
Channel 3	113.05	116.01	2.97
Channel 4	113.05		

Table 4-8. Improvement in SNR With 4-Channel Summation and DRE Disabled

SNR	Pre-Summation (dB)	Post-Summation (dB)	Improvement (dB)
Channel 1	112.94	118.99	5.92
Channel 2	112.94		
Channel 3	113.05		
Channel 4	113.05		

Table 4-9. Channel Summation to Boost Device SNR and Dynamic Range for TLV320ADCx1x0 Audio ADC Family

Device	Device SNR/ Dynamic Range (default) (dB)	Device SNR/ Dynamic Range (with 4-channel summation) (dB)	Device SNR/ Dynamic Range (with 2-channel summation) (dB)
TLV320ADC6140	With DRE: 123 dB	With DRE: 129 dB (Mono-mode)	With DRE: 126 dB (Stereo-mode)
	Without DRE: 113 dB	Without DRE: 119 dB (Mono-mode)	Without DRE: 116 dB (Stereo-mode)
TLV320ADC5140	With DRE: 120 dB	With DRE: 126 dB (Mono-mode)	With DRE: 123 dB (Stereo-mode)
	Without DRE: 108 dB	Without DRE: 114 dB (Mono-mode)	Without DRE: 111 dB (Stereo-mode)
TLV320ADC3140	106 dB	112 dB (Mono-mode)	109 dB (Stereo-mode)
TLV320ADC6120	With DRE: 123 dB	N/A	With DRE: 126 dB (Mono-mode)
	Without DRE: 113 dB	N/A	Without DRE: 116 dB (Mono-mode)
TLV320ADC5120	With DRE: 120 dB	N/A	With DRE: 123 dB (Mono-mode)
	Without DRE: 108 dB	N/A	Without DRE: 111 dB (Mono-mode)
TLV320ADC3120	106 dB	N/A	109 dB (Mono-mode)

These measurements are performed with AC coupled, differential line inputs, which result in dynamic range and SNR improvements of approximately 6 dB for 4 channel-summation and approximately 3 dB for 2 channel-summation. Similar channel-summation feature is available in the audio ADCs listed in Table 4-8 with expected improvement in dynamic range as well as SNR.

5 Summary

In summary, every doubling of the number of ADCs used in parallel increases the dynamic range and SNR performance by approximately 3 dB. The TLV320ADC6140, TLV320ADC5140, TLV320ADC3140, TLV320ADC6120, TLV320ADC5120, and TLV320ADC3120 from Texas Instruments feature an in-built channel-summation feature. This application note details a method to increase the dynamic range and SNR performance of audio ADCs using this in-built channel-summation feature.

6 References

- Texas Instruments, *TLV320ADC6140 Quad-Channel, 768-kHz, Burr-BrownTM Audio ADC*, data sheet.
- Texas Instruments, *TLV320ADC5140 Quad-Channel, 768-kHz, Burr-BrownTM Audio ADC*, data sheet.
- Texas Instruments, *TLV320ADC3140 Quad-Channel, 768-kHz, Burr-BrownTM Audio ADC* , data sheet.
- Texas Instruments, *TLV320ADC6120 Stereo-channel, 768-kHz, Burr-Brown™ audio analog-to-digital converter (ADC) with 123-dB SNR*, data sheet.
- Texas Instruments, *TLV320ADC5120 Stereo-channel, 768-kHz, Burr-Brown™ audio analog-to-digital converter (ADC) with 120-dB SNR*, data sheet.
- Texas Instruments, *TLV320ADC3120 Stereo-channel, 768-kHz, Burr-Brown™ audio analog-to-digital converter (ADC) with 106-dB SNR*, data sheet.
- Texas Instruments, *PCM6xx0-Q1 Automotive, 4-Channel and 6-Channel, 768-kHz, Audio ADC With Integrated Microphone Bias and Input Fault Diagnostics* data sheet.
- Electronic Products, *Practical considerations for estimating SNR and SFDR*, Arash, L. (2018).

7 Revision History

Changes from Revision * (June 2023) to Revision A (November 2023) **Page**

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