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Sigma Delta Converter

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***Abstract*—This paper portrays the concepts of Sigma-Delta converters. Conventional Nyquist-rate converters require analog components that are highly immune to interference and noise. On the other hand Sigma-Delta converters can be implemented by using simple and high-tolerance analog components. Sampling at oversampling rate in Sigma-Delta converters eliminate the need for abrupt cut-offs in the analog anti-aliasing filters. Noise shaping and oversampling technique is used in Delta sigma converters to achieve a high-resolution conversion.**

***Index Terms*— Analog-to-Digital converter (ADC), Decimation, Noise shaping, Oversampling, Pulse-code-modulation (PCM), Sigma-Delta.**

I. INTRODUCTION

Analog-to-Digital converters (ADCs) are key components in many modern electronic systems. They provide the critical translation of a measured analog signal to a digital representation. Once in digital form, the data can be easily and accurately processed to extract the desired information. The process of converting the analog signal to a digital signal often limits the speed and resolution of the overall system. As a result, there is a need to develop ADC that achieves both high speed and resolution [1]. There are several architectures of analog-to-digital converters have been developed by covering a high spectrum of application range in terms of design features such as sampling rate as well as resolution. However, mostly widespread ADC architectures have shown dramatic limits intrinsic to conversion principle also in their last enhancements. A promising role in overcoming current ADC limits (especially in terms of resolution and noise-free bandwidth) has been played by the sigma-delta conversion principle [2]. With the invention of Pulse Code Modulation (PCM) it becomes possible to start work on Sigma-Delta converters. The key feature of Sigma-Delta converter is there low cost conversion method which provides high dynamic range as well as flexibility mainly when used to convert low bandwidth input signals. Sigma-Delta devices are based on oversampling as well as on (quantization) noise shaping technique. There are two advantages of using oversampling. Firstly, the use of the anti- aliasing filter is reduced from the Nyquist specification (i.e. the sharp cut-off analogue filters required with Nyquist- rate DSP systems can be replaced with slow roll-off RC circuits). Secondly, the N-bit resolution obtained from an ADC can be increased to (N+1) bits by oversampling the signal by a nominal factor of 4 and subsequently digitally low-pass filtering to the Nyquist rate. Noise shaping is a technique, in which, the feedback architecture of an oversampling Sigma-Delta converter allows the input signal of interest to pass unfiltered through the converter but high-pass filter, filters the quantization noise. Hence, if the quantization noise has been filtered out of the baseband, the signal of interest can be extracted with more resolution than is achievable without noise shaping [3].

II. SIGMA DELTA MODULATOR

Nyquist-rate ADC samples the input analog signal at the $f_s=2f_m$, where f_m is the highest frequency component of the input signal and f_s is the sampling frequency. If the input signal is not band-limited then to prevent aliasing, an anti-aliasing filter must be used before the converter. An anti-aliasing filter must have a very narrow transition band to ensure that the filtered signal does not contain any frequency component above $f_s/2$. But it is very difficult to realize narrow transition band anti-aliasing filter. But Nyquist rate converters have low resolution which is not suitable for a very low voltage signal conversion. Oversampled ADC architecture is preferred over Nyquist rate ADC due to their high signal to noise ratio and high resolution. For moderate speed applications such as voice communicate or digital audio technology, oversampled ADC architecture is most preferable as compared to Nyquist rate converters [4]. In case of Sigma-Delta ADC the modulator portion behaves like a noise shaper and digital filter removes the out of band quantization noise thus ensure much higher SNR which is impossible to achieved in Nyquist rate ADC [5]. In addition to improve SNR, oversampling possesses inherently the motivation for prediction. The signal does not change significantly in the interval between successive samples when it is oversampled. This can lead a reduction in the number of quantization levels if the difference of two consecutive samples is encoded [6]. Since the values of these samples are very close, they are highly correlated and therefore future samples could be predicted from the past one. The simplest predictive modulator is the linear Delta modulator. A further improvement in the SNR can be achieved by pushing most of the in-band noise outside the signal frequency band. This is attainable if signal transfer function is a low pass whereas and Noise transfer function is high pass. This technique is called noise shaping and can be easily and efficiently implemented by modifying the delta modulator [7]. Here the integral of the input signal is encoded rather than the input signal directly. Clearly integration being a linear function does not affect system transfer function. The demodulation integrator at output can be placed at the input of Delta modulator. The significant modification of Delta modulation system is that matching of two integrator is not require any more and this new system is called Delta Sigma Modulator [1] as shown in Fig. 1 .

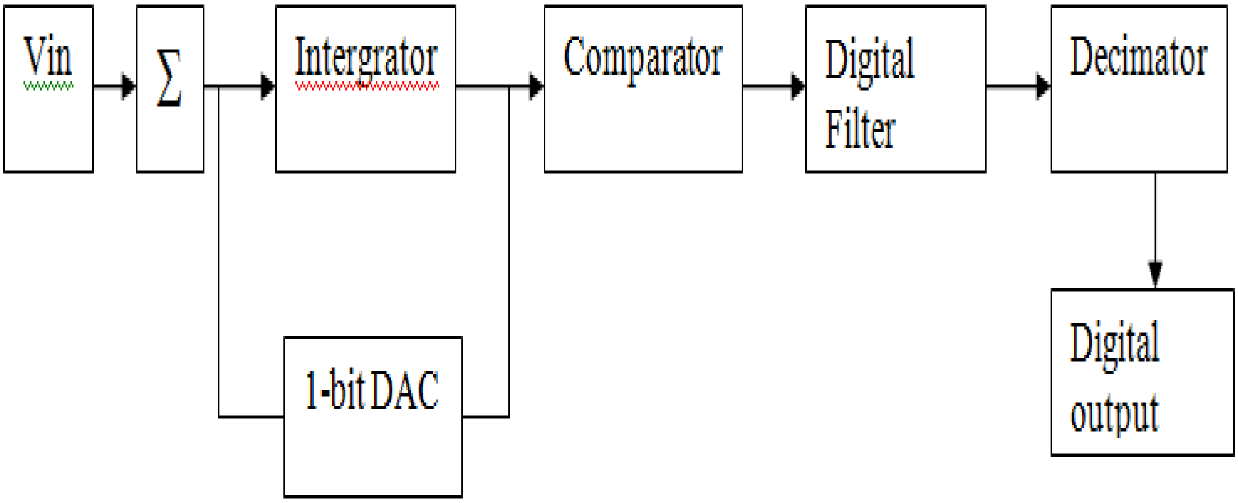
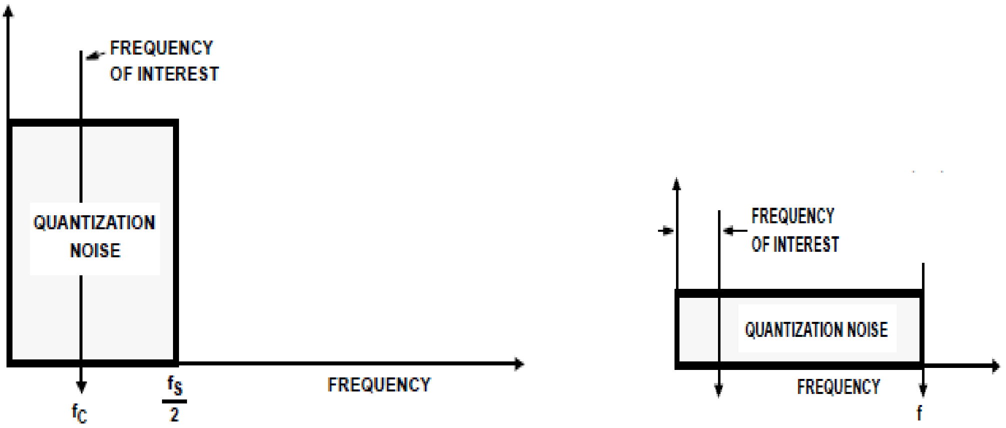


Fig.1. Delta Sigma modulator

III. NOISE SHAPING TECHNIQUE

For getting high resolution, high SNR must be maintained. And in order to maintain high SNR, quantization noise in effective bandwidth of interest must be maintained. The Sigma-Delta modulator is designed to suppress quantization noise in the baseband [5]. Thus, most of the quantization noise spreads, at frequencies above the baseband. The main objective of the digital filter is to remove out-of-band quantization noise. Thus a small amount of baseband quantization noise is left and the input signal becomes band limited component. Reducing the baseband quantization noise is equivalent to increasing the effective resolution of the digital output [6].



(a) Nyquist rate conversion **(b) Oversampled conversion**

Fig. 2. Comparison of Quantization Noise b/w (a) Nyquist-rate and (b) Oversampled conversion [9]

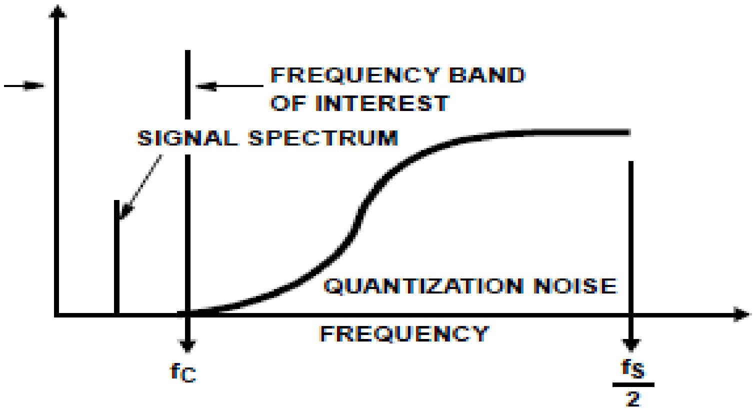


Fig.3. Noise shaping effect [9]

The noise-shaped Sigma-Delta converter in frequency domain is shown figure 4. The linear model is composed of the input signal, X(s), the analog filter, H(s), noise source, N(s), and the output signal, Y(s) [5]. Working of noise shaping technique in Sigma-Delta converter, to shift the noise at spectrum at higher end is shown below:

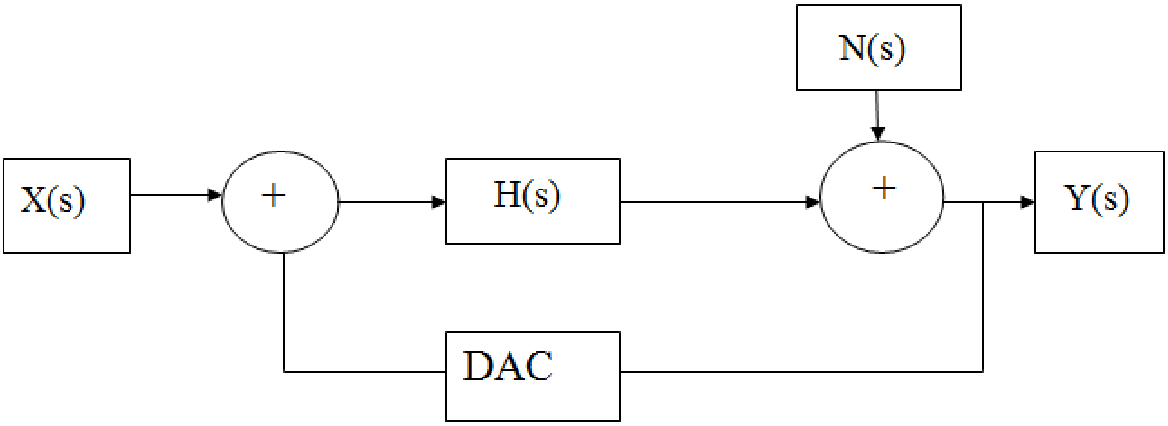


Fig 4. Linear model of noise shaped Sigma- Delta

Case-1: Transfer function when looking from X(s) and considering N(s)=0

$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1+H(s)} = \frac{\frac{1}{s}}{1+\frac{1}{s}} \qquad ---(1)$$

$$\frac{Y(s)}{X(s)} = \frac{1}{s+1} \qquad ---(2)$$

Equation (2) shows that digital filter act as Low-pass filter for input signal X(s).

Case-2: Transfer function when looking from N(s) and considering X(s)=0

$$\frac{Y(s)}{X(s)} = \frac{1}{1+\frac{1}{s}} = \frac{s}{s+1} \qquad ---(3)$$

Equation (3) shows that digital filter act as high-pass filter for noise source N(s). [9]

IV. CONCLUSION

Sigma-Delta conversion technique is used to produce high resolution and high signal-to-noise ratio. This paper gives introduction to the Sigma-Delta conversion process. Oversampling reduces the amount of quantization noise present in the signal band and noise shaping technique further attenuates quantization noise in the required band of interest by pushing noise to out-of-band frequencies. The use of analog filtering combined with feed- back around the ADC can be used to implement the noise shaping sigma-delta modulator. The noise power that is pushed outside the signal band can be attenuated by a digital filter such that it has no further effect on the signal. Thus sigma delta converter grossly oversamples the input signal and shapes the noise spectrum such that the modulator appears to be a high pass filter for the noise and a low pass filter for the input signal. This leads to increase in signal-to-noise ratio and resolution.

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