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Implementation of Sigma-Delta Modulator using 120 nm Technology

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Abstract—*The Sigma-Delta A/D converters have been proposed as a practical application for A/D conversion at high rates because of its simplicity and robustness to imperfections in the circuit, also because the traditional converters are more difficult to implement in VLSI technology. These difficulties with conventional conversion methods need precise analog components in their filters and conversion circuits, and are more vulnerable to noise and interference. This paper aims to analyze the architecture, function and application of Analog-Digital converters (A/D) Sigma-Delta to overcome these difficulties, showing some simulations using the Simulink software and tanner tool..*

Keywords—**Analysis, Oversampling Modulator, A/D converters, Sigma-Delta.**

Introduction

sigma-delta conversion [1]-[3] technique exists for several years but its most extensive use was made possible due to technological advances like the advent of digital signal processors implemented in VLSI technology [4], which brought the need for A/D converters, high-resolution that could be integrated into the manufacturing process optimized for digital circuits and systems. In the literature, we can find several application and research [5], [6]. In addition, the implementation of sigma-delta conversion was made possible by the continuous improvement in digital signal processors, also in order to mitigate limits in the dynamic range available for the implementation of the interfaces between analog and digital representation of signals. The A/D converters based on sigma-delta modulation (ΣΔ) [5], [6] combine high sampling rates with the Nyquist frequency with feedback and digital filtering in order to exchange resolution in time for amplitude. These converters are insensitive to circuit imperfections and component mismatches since they employ only a simple two-level quantizer and embedded quantizer within a feedback loop. A ΣΔ modulator [7], therefore, provide a mean of exploring the higher density and speed of VLSI digital circuits, to avoid the difficulty of implementing complex functions of analog circuits within a limited dynamic range analog [6]. A ΣΔ modulator consists [7] of an analog filter, quantizer with a negative feedback. The feedback acts to reduce the noise of quantization at low frequencies, while emphasizing the high frequency noise.

Once the signal is sampled with a frequency that is much larger than the Nyquist rate, the quantization noise of high frequency can be removed without affecting the signal bandwidth by a digital low-pass filter operating in ΣΔ modulator output. The modulator has first order, whereas the filter consists of a simple integrator. However, the quantization error of the first order modulator is highly correlated and the oversampling ratio to achieve a higher resolution than 12 bits is incredibly high. First order modulator can be extended to higher orders. In this work a first order ΣΔ converter will be analyzed and simulated to show the simplicity and scalability.

II. DIGITAL MODULATION

The principles of operation of A/D Sigma-Delta [1]-[4], are linked to concepts that will be demonstrated in the following topics.

A. Quantization

First, amplitude quantization and sampling in time are the important parts of digital modulators. Regular sampling at rates greater than twice the bandwidth of the signal does not introduce distortion, but the quantization introduces. The primary objective in the design of modulators is to limit this distortion. Starting a description of some basic properties of quantization will be useful to specify the noise modulators. Fig. 1 shows the uniform quantization of a ramp signal and its quantization error [1]-[7].

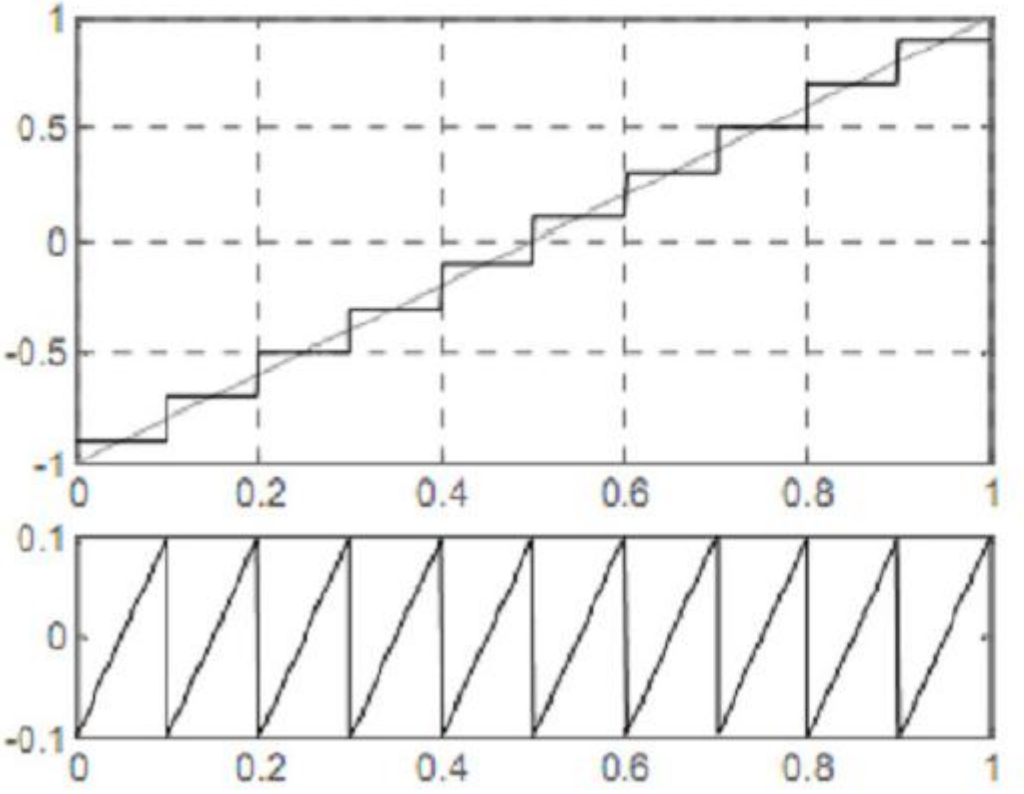

Fig. 1 (a) Ramp Signal; (b) Quantization error

It will be useful to represent the signal quantized x by a linear function G with an error e then we have:

$Y = G_x + e$

The gain G is the slope that passes through the center of the quantization characteristic then, if the quantizer does not saturate, the error is bounded by $\pm\ \Delta/2$. The error is completely defined by the entrance, but if the input changes randomly between the samples in amounts comparable to or exceeds the threshold spacing without causing saturation, then the error is uncorrelated from sample to sample and has equal probability of being anywhere in the range $\pm\ \Delta/2$. If we assume that the statistical error has properties that are independent of the signal, then we can represent it by a noise, and some of the most important modulator properties can be determined. In many cases, experiments can confirm these properties, but there are two cases that cannot apply these concepts. Note that, if the input is constant or when changes regularly by multiples or submultiples of the size of the sampling step, for example as in feedback circuits. The quantization error e has an equal probability of being anywhere in the range ± Δ/2, its average value is given by:

$$e_{RMS}^2 = \frac{1}{\Delta}\int_{-\Delta/2}^{\Delta/2} e^2 de = \frac{\Delta^2}{12}$$

We use a one-sided representation of frequencies, in other words, we assume that all power is in the range of positive frequencies. When a quantized signal is sampled in the frequency fs=1/T, all energy is concentrated in the frequency range 0 ≤ f < fs/2 So, if the quantization noise spectral density is white noise, the samples are given by:

$$E(f) = e_{RMS}\sqrt{\frac{2}{f_s}} = e_{RMS}\sqrt{2T}$$

We can use this result to analyze examples of oversampling modulators. A signal in the frequency range 0 ≤ f < fo, for a sign contained in the band fo ≤ f < fs / 2 is added, it needs to be modulated by fs. The oversampling ratio (OSR), defined as the ratio of the sampling frequency fs and the Nyquist frequency 2fo is given by:

$$OSR = \frac{f_s}{2f_o} = \frac{1}{2f_oT}$$

If the signal excitation is sufficiently large and uncorrelated the quantization error, the noise power that falls into the signal band will be given by:

So as result of the oversampling, the noise entry reduces. Therefore, each sampling frequency double reduces the input noise by 3dB, increasing the resolution in only half a bit.

B. First-Order Feedback Quantizer

An oversampling quantizer more efficient is the sigma delta modulator (ΣΔ) shown in Fig. 2 [1].

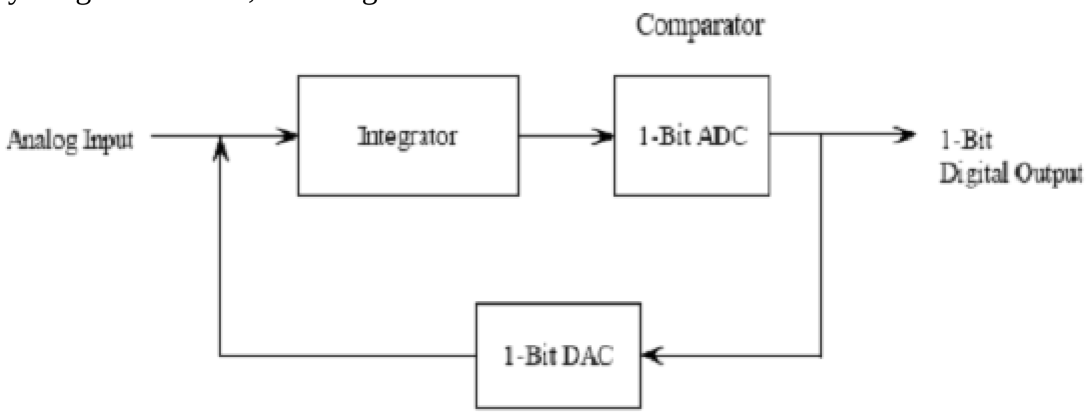

Fig. 2 Block diagram of a first order sigma-delta modulator.

The ΣΔ modulators usually are used with two quantization levels. In this work will be used a first-order modulator to demonstrate the operation of these converters. The input circuit feeds the quantizer via an integrator and the quantized output is feedback to a subtraction of the input signal. This feedback forces the average value of the quantized signal to achieve an average value of the entry. Any persistent difference between the two is the accumulative error in the integrator that eventually corrects it.

C. Modulation Noise in Busy Signals

Analysing the sigma-delta modulator block diagram depicted in Fig. 2, we can add a signal which represents the quantization error of the

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equation and a gain G defined as quantization unit.

Because of these data samples of the circuit, we represent the integration of accumulation, also with a unity gain. Can easily be shown that the output of the accumulator is:

$$w_i = x_{i-1} - e_{i-1}$$

and the quantized signal is:

$$y_i = x_{i-1} + (e_i - e_{i-1})$$

Then the circuit differentiates the quantization error, making the error of modulating the first difference of the quantization error while leaving the signal unchanged, except if there is any delay. To calculate the effective resolution of the ΣΔ modulator, we assumed the signal has white noise, which is the error is uncorrelated with the signal. The spectral density of the modulation noise can be expressed as:

$$n_i = e_i - e_{i-1}$$

$$N(F) = E(F)\left|1 - \varepsilon^{-j\omega T}\right| = 2e_{RMS}\sqrt{2T}\sin\left(\frac{\omega T}{2}\right)$$

In the Fig. 3, we compare the spectral density with the spectral density of quantization noise when the oversampling ratio is 16. Clearly, the feedback around the quantizer reduces the noise at low frequencies but increases at high frequencies.

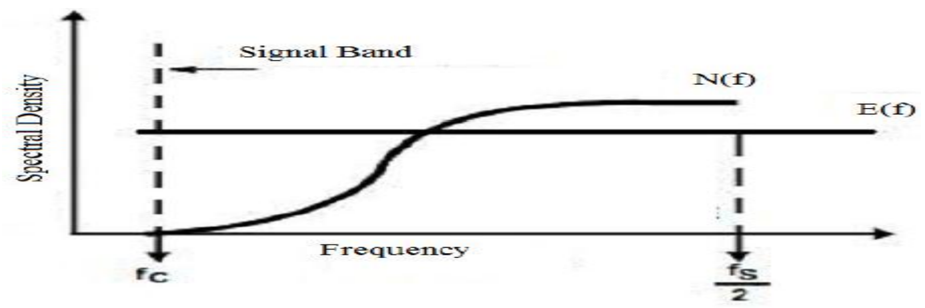
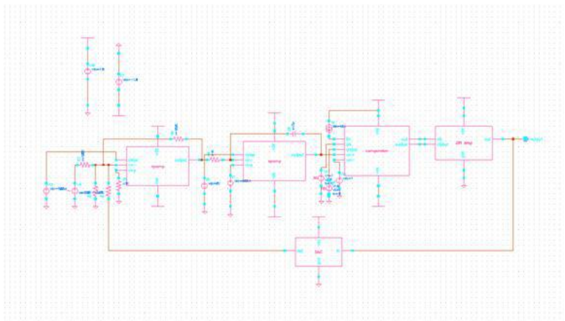


Fig. 3 The density of the noise N(f) from ΣM quantization compared with that of ordinary quantization E(f).



The total noise power in the signal band is given by:

$$n_0^2 = \int_0^{f_0} |N(f)|^2 df \approx e_{RMS}^2 \frac{\pi^2}{\sqrt{3}} (2f_0T)^3 f_s^2 \gg f_0^2$$

Each oversampling ratio by a factor of 2 in this circuit reduces noise by 9dB and increases 1.5 extra bits in resolution. The improvement of the resolution requires that the modulated signal is decimated to the Nyquist frequency using a digital selective filter. Otherwise, the components of high frequency noise will affect

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the resolution when it is sampled in the Nyquist frequency.

In [2] [3], we find how the RMS noise of a PCM signal can

be expressed as

$$\sqrt{2}e_{RMS}(2f_0T)$$

Therefore taking a triangularly weighted sum over each Nyquist interval gives an RMS noise is

$$4e_{RMS}(2f_0T)^{1.5}$$

An optimization of these techniques for attenuating the high frequency noise is demonstrated in [4]. This decimation allow more noise in the signal band than those using filters with impulse response that are longer than a Nyquist interval, but such techniques have been used because of simple circuit implementation.

III. PROJECT OF A ΣΔ CONVERTE

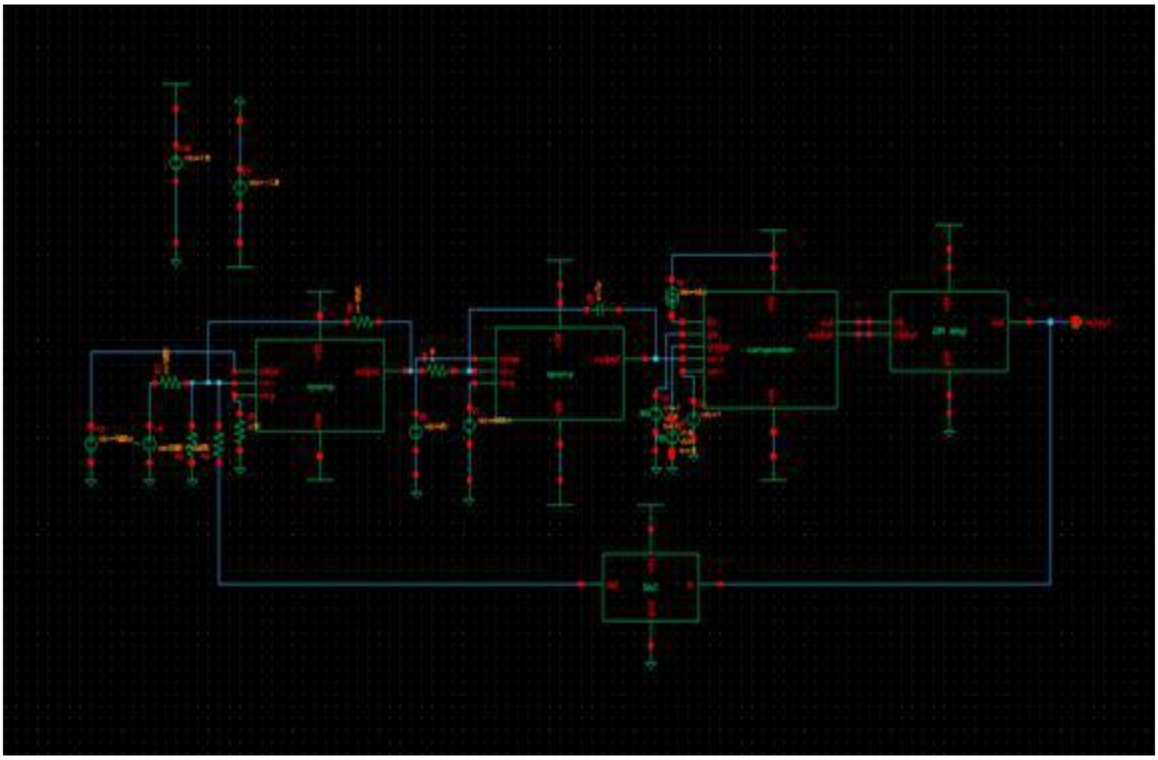

Fig. 4 First order ΣΔ modulator

In this work will show a ΣΔ converter, demonstrating the implementation of each part of the circuit according to the theory explained in the previous sections. A ΣΔ converter is always composed of decimation filters and a modulator, which produces the bitstream data.

The bit-stream data signal is represented by a series of bits, with a rate much higher than the data rate of the A / D. Its main property is the average that represents the input signal level. Its digital outputs high and low are, respectively, the highest and lowest possible output values. The ΣΔ modulator is the core of oversampling ΣΔ converters, this part produces a continuous stream of bits.

In this work we designed a first order modulator which it is enough to demonstrate the features of this type of modulation.

Higher-order modulators can be implemented from that, just using a cascade configuration. In Fig. 4 can be seen a model of a first order ΣΔ modulator.

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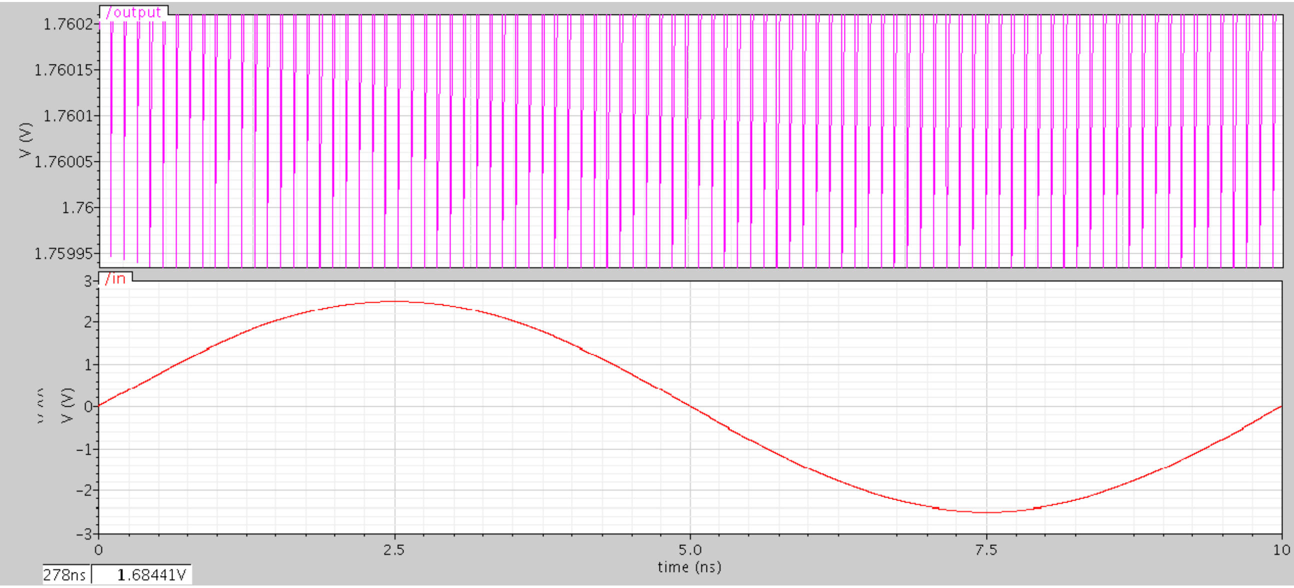

Fig. 6 Signals within a First Order Analogue Modulator

This work has being done to convert a sine wave of 1V amplitude with a frequency of 3.4 kHz in order to simulate how it would be a conversion of a voice signal. The comparator checks if the output of the integrator is greater than 0 and is given a pulse of 5V to feed the flip true, otherwise it is issued 0V output from the comparator.

The oversampling frequency is controlled by the clock used in the flip-flop, in our case the Nyquist frequency fs = 8 kHz is the sampling frequency used for most voice signals. In this context the oversampling frequency used is 64 times the Nyquist frequency. For these parameters the clock of the modulator is 512 kHz. For the 1-bit D/A encoder which is used in the feedback we used a comparator to check the flip flop output. If the output is 0, the comparator uses the reference voltage of 1V and transforms the signal 0 to the flip-flop is one; its voltage is 5V which was lowered to the reference voltage of 1V.

In modulator's output was inserted a block that keeps a constant frequency at 512 kHz for the decimation process. Was also inserted a delay entry block in order that the comparison could be made between input and output of the converter to demonstrate the quantization error. This comparison can be seen in Fig. 6. The output of decimation provides a digital signal that follows the same waveform input.

IV. CONCLUSION

Through the theories and simulations we can verify the functionality and applicability of the A/D converters of the type Sigma-Delta, emphasizing its simplicity of implementation, conversion speed of the analog signal to digital and the improvement in signal to noise ratio compared to other types of converters A/D. Although, the Sigma-Delta modulator has been introduced in 1962, only recently with the advent and advancement of VLSI technology it has gained importance. The increasing use of digital techniques also contributed to the effective use of A/D converter high accuracy.

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