

Modeling techniques currently utilized in design of

$\Sigma\Delta$ - Modulator are based on MATLAB

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Abstract

Sigma-Delta ($\Sigma\Delta$) Analogue-to-Digital Converters (ADC) have been hugely successful in realizing high-resolution consumer audio products, such as MP3 players and cellular mobile phones, for some time now.

*Matlab*⁷ offers a technical computing environment for high-performance numeric computation. It integrates numerical analysis, matrix computation and graphics in an easy-to-use environment without the use of tedious language syntax. The *Matlab* environment is ideal for the behavioral simulation of $\Sigma\Delta$ converters because signals can be treated as vectors (matrices with only one row or column) and the modulator operation itself can be described simply as a set of difference equations. The output bit stream(s) from the modulators can be easily transformed into the frequency domain by making use of *Matlab*'s excellent signal processing functions, such as the various windowing functions and the Fast Fourier Transform (FFT). Furthermore the results can be displayed graphically and the noise and signal components can be quickly summed up separately to compute the SQNR. An example of the difference equation modeling of a 3rd order feed- forward modulator (using a 4-level quantile and over sampling rate of 76.8) is shown in Figure2 along with the output spectrum and the computed SQNR.

1. INTRODUCTION

There is a great deal of interest in extending the bandwidth of sigma-delta-modulators for wideband applications. There are many ways to increase the bandwidth of a sigma-delta converter. Each method involves an alteration of one or more of the parameters available to the designer, that is the sampling frequency, the number of bits in the quantizer, the oversampling ratio and the modulator loop order. An alternative to increase the effective sampling frequency is to lower the OSR. There are several ways to do so. One solution is to improve the noise-shaping characteristic by employing higher-order modulators, [1]. Another alternative and perhaps the most practical approach, is to replace the single-bit quantizer by a multi-bit quantizer, [2]. This allows the OSR to be reduced without trading resolution to

maintain stability. One approach to escape the DAC nonlinearity effects is to cascade a single-bit and a multi-bit modulator [1].

2. SYSTEM-LEVEL SIMULATION BY SIMULINK

Fig. 1 shows the block diagram of a traditional third order 5-bit- modulator. Fig. 2 shows the block diagram of the third order 5-bit-modulator that is proposed in this work .The noise-shaping filter is a third-order topology with a cascade of integrators in a single loop and a feedforward signal path. This topology differs from the previous third-order-modulators. The feedforward signal path concept [3] has been extended to third-order noise shaping to realize a reduced sensitivity to opamps nonlinearities and to relax the stability requirements.

In the traditional third-order- modulators the output is given by:

$$Y(z) = z^{-3} \cdot X(z) + (1 - z^{-1})^3 \cdot Q(z) \quad (1)$$

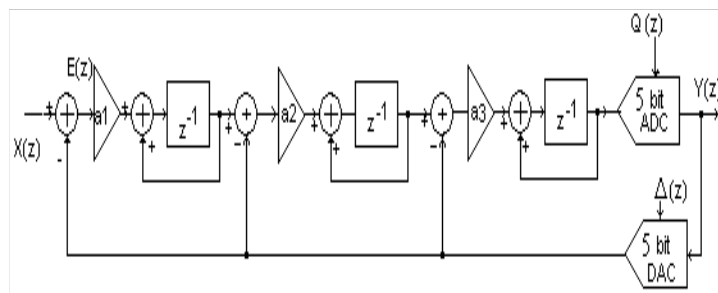


Figure 1. Block diagram of the traditional 3rd order 5-bit- modulator

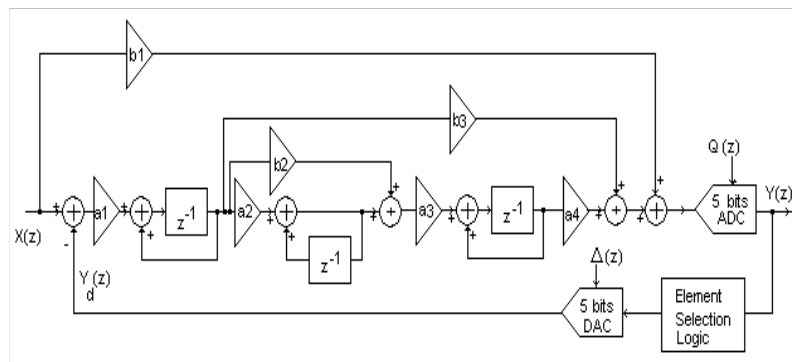


Figure 2. Block diagram of the 3rd order 5-bit - modulator with feedforward path

The signal transfer function is $STF(z) = z^{-3}$ and the noise transfer function is $NTF(z) = (1 - z^{-1})^3$. In this case the harmonics of the input signal created due to the nonlinear opamps will appear at the modulator output shaped by third-order high-pass transfer function. In wideband applications, the attenuation provided by a 3rd order high-pass transfer function at a low oversampling ratio is not enough. One solution is to design low distortion opamps.

In the-modulator with feedforward path the nonlinearity problem is achieved by making the signal transfer function, $STF(z)$ exactly equal to 1.

The proposed topology combines the advantage of sigma-delta modulator with feedforward path and the multibit quantizer to achieve high dynamic range and wideband A/D conversion. This topology uses only one DAC in the feedback path. This advantage is very important for multibit quantizer because of this reduces the complexity of circuit and the chip area. Another advantage of this topology is that the integrators process quantization noise only and than their performance requirements are relaxed.

By applying linear analysis, the output of the third orde-modulator with feedforward path is given by

$$Y(z) = STF(z) \cdot X(z) + NTF(z) \cdot Q(z) \quad (2)$$

where the signal transfer function must be $STF(z) = 1$, without changing the third-order noise transfer function, $NTF(z)$.

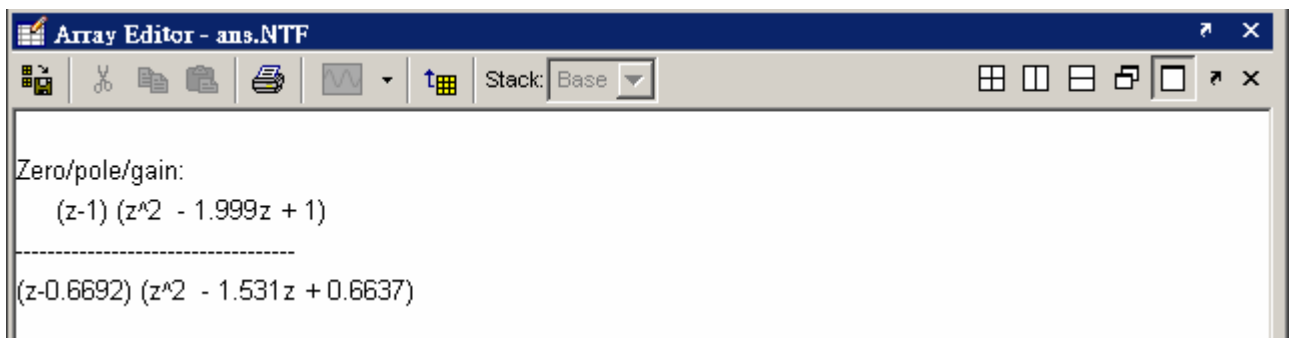
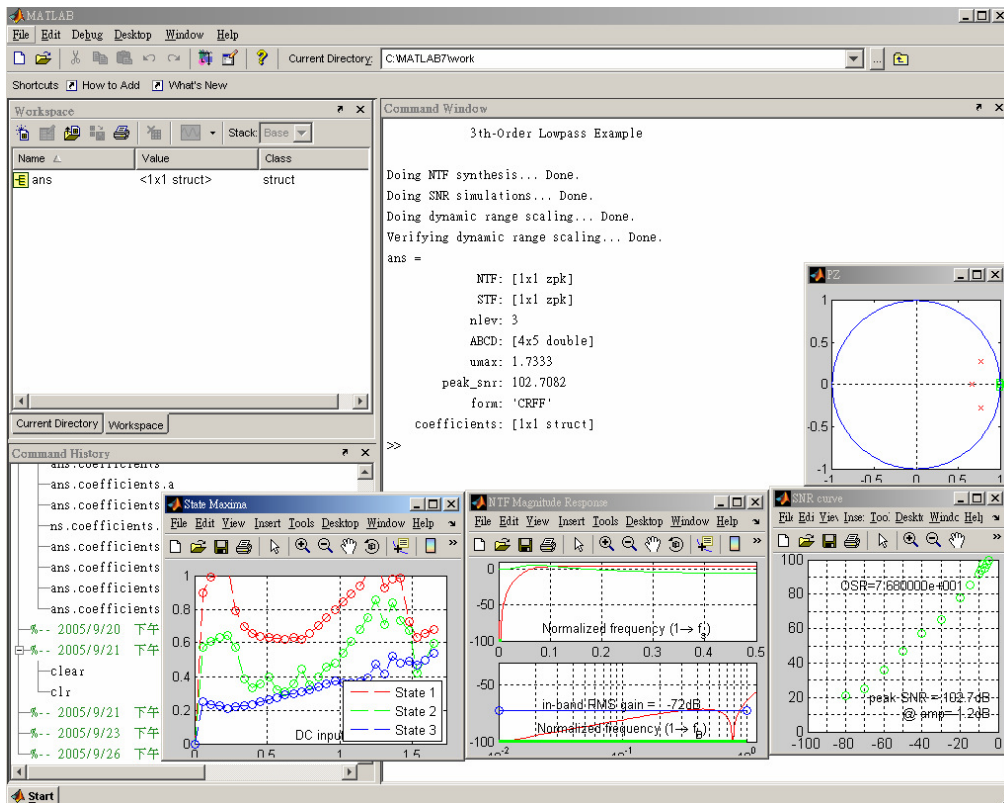
The noise transfer function for the topology presented in Fig. 1 is:

$$NTF(z) = \frac{(1 - z^{-1})^3}{D(z)} \quad (3)$$

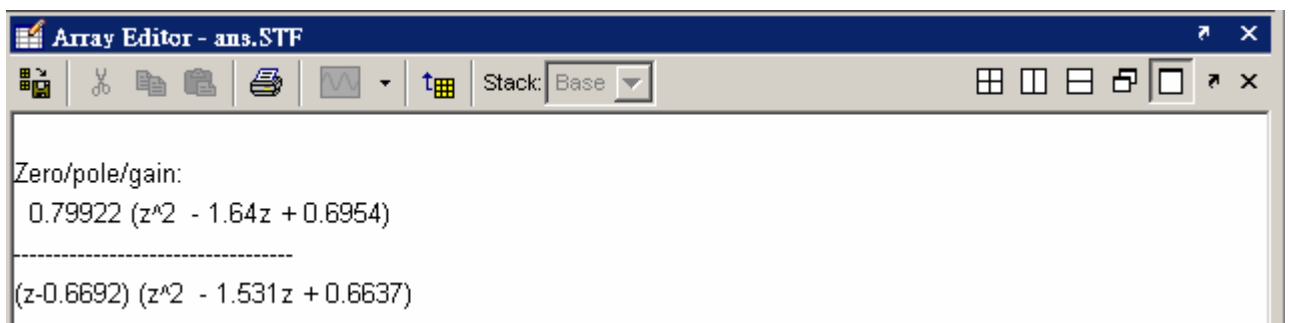
where for $b_1 = 1$, $D(z)$ is

$$\begin{aligned} D(z) = & 1 + (a_1 b_3 - 3) \cdot z^{-1} + \\ & + [3 - 2a_1 b_3 + a_1 a_3 a_4 (a_2 + b_2)] \cdot z^{-2} \quad (4) \\ & + (a_1 b_3 - a_1 a_3 a_4 b_2 - 1) \cdot z^{-3} \end{aligned}$$

The design of 3rd order multibit-modulator with feedforward path was done using the CLANS methodology [1], and several MATLAB simulations [4]. The coefficients were chosen for generating the peak SNDR of the modulator and to guarantee that the baseband quantization noise is independent of the input signal. By using the Sigma-Delta ADC Toolbox of MATLAB in Figure 3, the final values for the coefficients are $a_1 = 1$, $a_2 = 0.7499$, $a_3 = 1$, $a_4 = 1$, $b_2 = 1.6374$, $b_3 = 2.6062$.



NTF



STF

Field	Value
a	[1.3447 1.913 3.4403]
g	0.010103
b	[0.41333 0 0 0]
c	[0.41333 0.30783 0.099363]

Coefficients

Figure 3. Sigma-Delta ADC Toolbox of MATLAB

3. Simulation and Measure Result:

To further aid the designer, an empirical study of high order $\Sigma\Delta$ -modulators has been conducted and has resulted in a CAD toolbox (based in Matlab and freely available) that allows $\Sigma\Delta$ -modulator design and performance simulations to be carried out with ease. In particular, the toolbox is comprised of various functions (written in *Matlab*) that allow the user to synthesize different discrete noise transfer functions and map these NTF onto different topologies so that the modulator coefficients can be determined. A further function is also available to optimize the NTF for a low-pass multi-bit $\Sigma\Delta$ -modulator based on the “Closed-loop Analysis of Noise-Shaper” (CLANS) method from. This function uses the optimization toolbox from *Matlab*. Figure 3 show the toolbox of ADC. Figure 4 show the Third order $\Sigma\Delta$ -modulator CIFB Structure, and Figure 5 and Figure 6 show the results of waveform of simulation and measure. Figure 7 and Figure 8 show the results of Frequency response of simulation and measure.

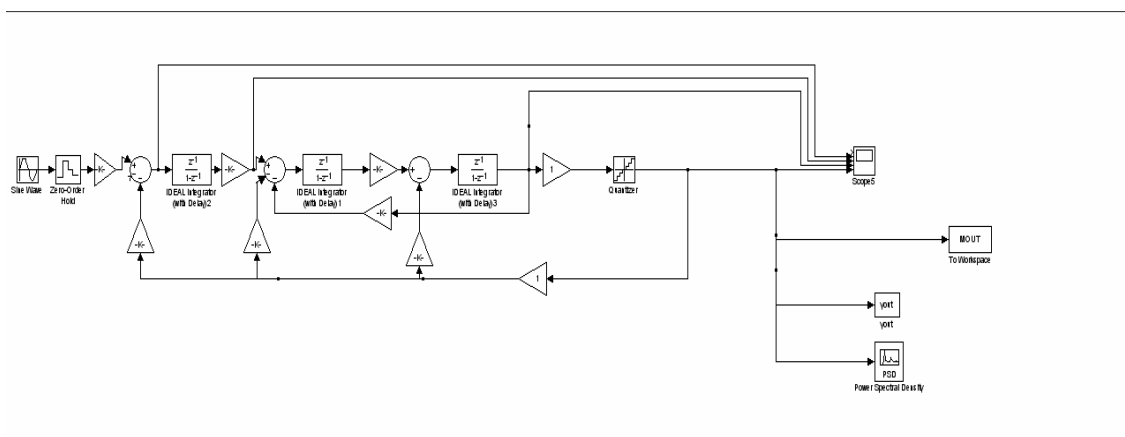


Figure 4. Third order $\Sigma\Delta$ -modulator CIFB Structure

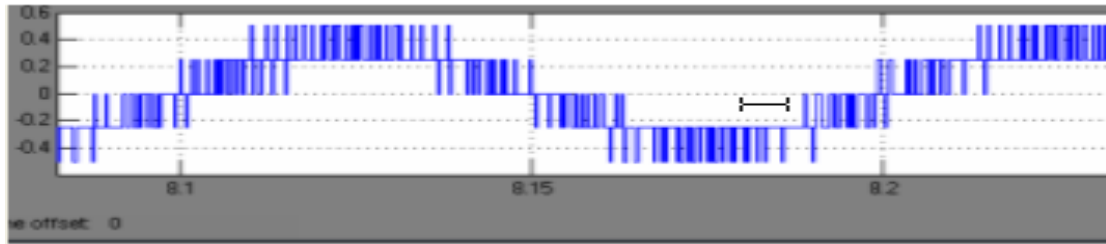


Figure 5. MATLAB simulation waveform

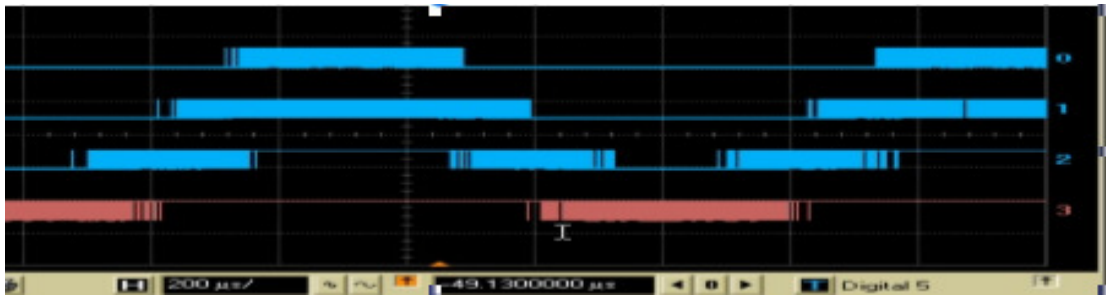


Figure 6. measure waveform

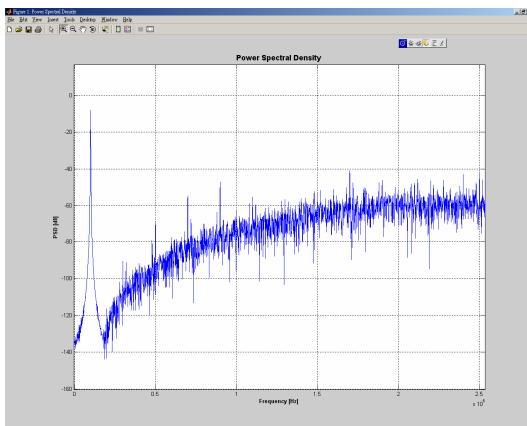


Figure 7. Frequency response by using Matlab

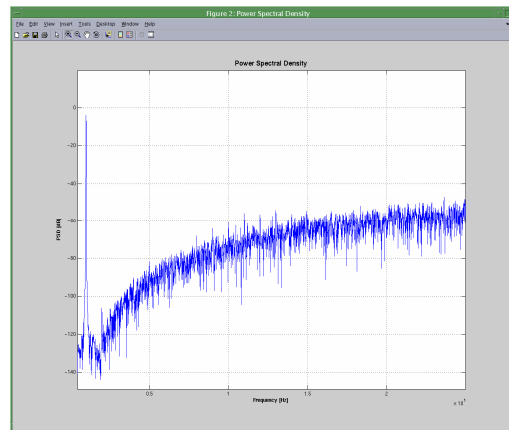


Figure 8. Frequency response of Implement by circuits

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