

A Novel $\Sigma\Delta$ Modulator Design Applied to Dual GSM/WCDMA Receiver

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ABSTRACT

A novel $\Sigma\Delta$ modulator is presented with lower power consumption and higher Signal to Noise Ratio (SNR) than the conventional modulator for a given order. The novel modulator is applied in analog-to-digital converters of RF receivers. The same modulator architecture is used for GSM and WCDMA receivers differing only the in Oversampling Ratio (OSR). The modulator was designed using switched capacitor circuits and could be implemented in VLSI.

1. INTRODUCTION

Sigma delta modulators trade resolution in time for resolution in amplitude such that the use of imprecise analog circuits can be tolerated. Although commercial sigma-delta A/D and D/A converters have been in existence for more than a decade now, the primary application of such converters has been in digital audio. The narrow bandwidths in digital audio applications have made oversampled converters particularly appealing. It is only recently, as we benefit from the increased speed of submicron devices, that sigma-delta modulators are exploited for wider band systems such as wireless RF communications [1-4].

New architectures and circuit techniques need to be explored in the design of fully integrated, multistandard RF transceivers. One of the more notable challenges lies in the design of low-power, high dynamic range baseband blocks which will coexist on the same substrate as the RF front-end components. The wide dynamic range is necessitated by the elimination of discrete high-Q SAW filters in traditional receivers. A common structure of GSM receivers is based on the single Intermediate Frequency (IF) single superheterodyne (SSH) architecture shown in figure 1.

Sigma-delta modulators used in the ADC of the superheterodyne receiver are uniquely suited to fully-integrated RF baseband applications for two reasons. First, because their quantization noise is shaped with a high-pass characteristic, most of the noise energies fall in the same band as the undesired blockers. The same

digital decimation filter can therefore be used to attenuate both the quantization noise and the blockers [5]. Second, the same $\Sigma\Delta$ modulator architecture, differing only in the oversampling ratio, can be used to adapt to the different dynamic range and bandwidth requirements of multiple RF standards.

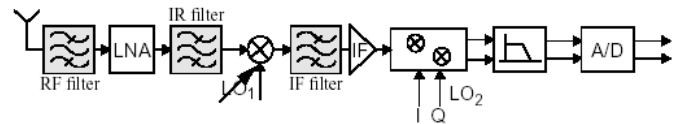


Fig.1. Single superheterodyne receiver

The same designed modulator is suitable for multi-standard systems since it is used in the GSM and WCDMA receivers. There is no need for separate hardware; the same architecture is used for both standards but with different Oversampling Ratio (OSR). Table 1 shows the ADC specifications for GSM and WCDMA at the baseband of the RF receiver [6].

Table 1. ADC specifications

	WCDMA	GSM
Signal Bandwidth	3.84 MHz	200 KHz
Dynamic Range (DR)	54 dB	86 dB
Signal to Noise Ratio (SNR)	53 dB	76 dB
Distortion Signal to Noise Ratio (DSNR)	52 dB	72 dB
Image Rejection (IR)	> 41 dB	> 40 DB
3 rd Intercept point (IP3)	18 dBVrms	26 dBVrms

2. NOVEL $\Sigma\Delta$ MODULATOR DESIGN

A novel modulator design having a controllable Signal to Noise Ratio (SNR) will be presented. Note that high order sigma delta modulators are usually designed using cascaded first and second order modulators. In this section, analytical derivations for the novel modulator are done for the first order only.

Figure 2 shows the block diagram of the conventional modulator with the quantizer having a

linear model [7] where $H(z) = 1/(1-z^{-1})$. The SNR is given by [8]:

$$\text{SNR} = 10\log_{10}(\sigma_{xy}^2) - 10\log_{10}(\sigma_{ey}^2) - \log_{10}\left(\frac{\pi^2}{3}\right) + 30\log_{10}\left(\frac{f_s}{2f_B}\right) \quad (1)$$

Where σ_{xy}^2 and σ_{ey}^2 are the signal power and error power at the output of the modulator, f_B is the maximum signal bandwidth and f is the sampling frequency. It is assumed that $f_B \ll f_s$. For every doubling of the oversampling ratio, the SNR improves by 9 dB.

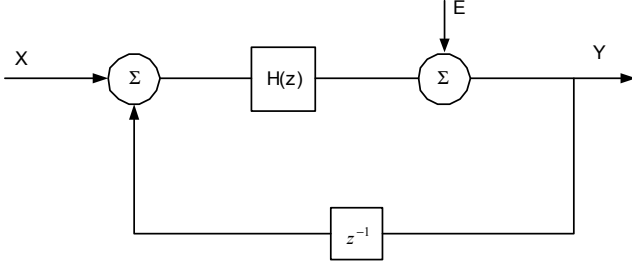


Fig. 2. Conventional modulator block diagram

The new modulator design is based on the observation that the block preceding the quantizer for noise shaping is just an accumulator that performs the function of an integrator in the analog domain. In the conventional modulator the discrete transfer function used is the discretization of the analog integrator $1/s$ using the rectangular rule.

Obviously, trying to get a better approximation of the integrator will yield a better modulator performance. Specifically, using the Al-Alaoui method by interpolating between the rectangular and trapezoidal rules to get the new discrete accumulator to be used in the novel modulator [9].

The proposed modulator uses a new integrator which is a combination of the rectangular and trapezoidal rule as follow:

$$H(z) = \alpha H_R(z) + (1-\alpha)H_T(z)$$

$$H(z) = \alpha \frac{T}{z-1} + (1-\alpha) \frac{T}{2} \frac{z+1}{z-1}$$

The general formula for the new integrator to be used will be:

$$H(z) = \frac{b + az^{-1}}{1 - z^{-1}} \quad (2)$$

The corresponding block diagram for the novel modulator is shown in figure 3. The Signal to Noise Ratio (SNR) for the new modulator is derived since it is used for testing the performance of sigma-delta modulators. The SNR is given by [10]:

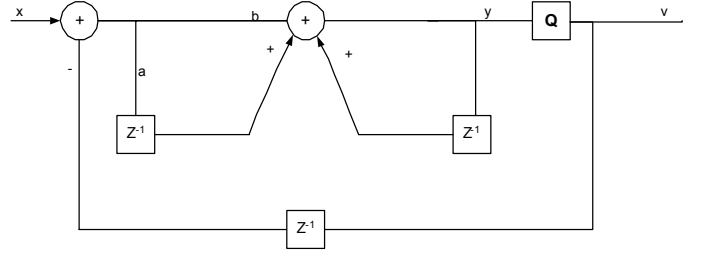


Fig 3. Novel modulator block diagram

$$\text{SNR}_{NEW} = 10\log_{10}(\sigma_{xy}^2) - 10\log_{10}(\sigma_e^2) - 10\log_{10}\left(\frac{\pi^2}{3}\right) + 30\log_{10}\left(\frac{f_s}{2f_B}\right) - 20\log_{10}\left(\frac{1}{a+b}\right) \quad (3)$$

To get a higher SNR than the conventional modulator the parameters a and b should be selected such that $(a+b) > 1$ producing a positive added term:

$$-20\log_{10}\left(\frac{1}{a+b}\right) > 0 \quad (4)$$

For example for $a = 0.5$ and $b = 1.5$, the SNR will be improved by 6 dB. The values of a and b cannot be increased indefinitely, rather a stability and optimization techniques are investigated [10]. The optimum values for a and b are found to be 1 and 3 respectively giving a SNR improvement equals to 12 dB. Figures 4 and 5 give the noise and signal transfer functions of both the conventional and novel modulators.

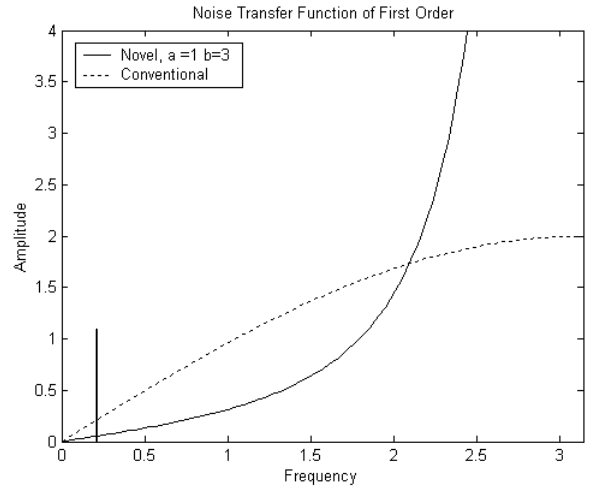


Fig. 4. Comparison of the noise transfer functions for a = 1 and b = 3

In sigma delta modulators, the oversampling ratio is at least eight. The vertical line in figure 4 indicates the

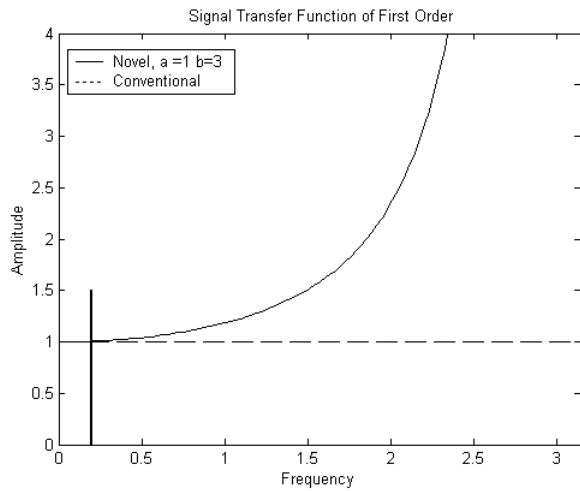


Fig. 5. Comparison of the signal transfer functions for $a = 1$ and $b = 3$

highest possible frequency available for such oversampling ratio. Note how the noise is much more attenuated in the case of the novel modulator. The noise is pushed into higher frequencies and is not a problem since a lowpass filter will be implemented in the digital domain along with the decimator [11].

On the other hand, the new designed modulator, does not have a constant signal transfer function over the whole frequency range; rather the STF is constant over the range of interest indicated by the vertical line as shown in figure 5.

Although we are getting high noise attenuation (for $a = 1$ and $b = 3$) and consequently a better signal SNR, we have a double pole at $z = -1$, which means that we are on the edge of instability. So due to non-idealities in the system, the modulator may become unstable. A possible remedy is to assign the parameters in such a way that we get a robust modulator with a considerably high noise attenuation without undesirable peaking; this is done by having the roots of the noise transfer function as a complex pair (i.e: $a = 0.3$ and $b = 1.7$). Figures 6 and 7 show the noise and signal transfer functions respectively for complex roots. A switched capacitor circuit implementation of the first order novel modulator is proposed in figure 8.

3. DESIGN EXAMPLE

In this section a modulator will be designed to be used in the Wideband IF Double Conversion receiver. The same modulator is used in the GSM as well as the WCDMA receiver, only the oversampling ratio has to be changed. The modulator for such application was designed by [6] using the conventional approach.

The objective is to reduce the order of the designed Burger's modulator [6] in order to save on the power dissipation. The new design will increase the oversampling ratio to benefit from the characteristics of the novel first order modulator. Tables 2 and 3 draw a

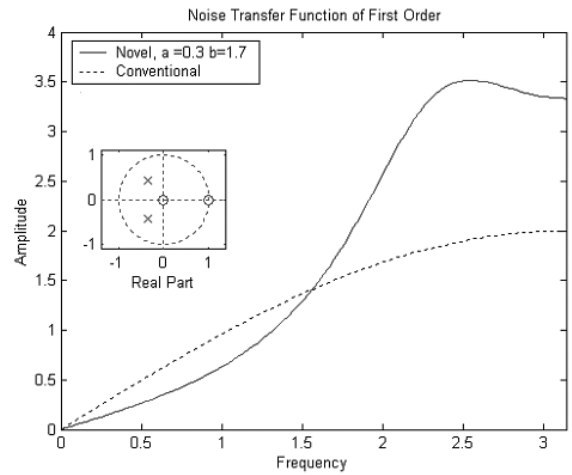


Fig. 6. Comparison of the noise transfer functions for $a = 0.3$ and $b = 1.7$.

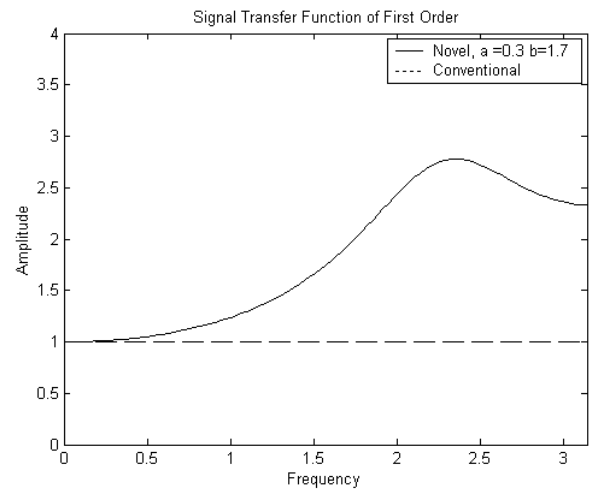


Fig. 7. Comparison of the noise transfer functions for $a = 0.3$ and $b = 1.7$

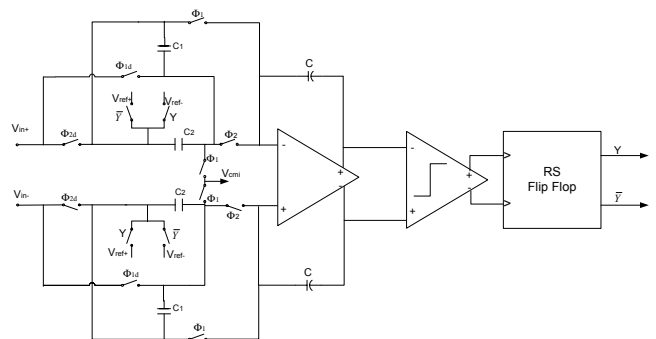


Fig. 8. Proposed circuit for the novel first order $\Sigma\Delta$ modulator

TABLE 2. Comparison between Berger and new designed modulator for WCDMA

	Berger Modulator	New Modulator
Topology	Single Loop	Single Loop
Order	3	1
Dynamic Range (DR)	55.9 dB	57 dB
Oversampling Ration (OSR)	24	96
Sampling Frequency	184.32 MHz	737.28 MHz
IF frequency	138.24 MHz	552.96 MHz
Signal Bandwidth	3.84 MHz	3.84 MHz

TABLE 3. Comparison between Berger and new designed modulator for WCDMA

	Berger Modulator	New Modulator
Topology	Single Loop	Single Loop
Order	3	1
Dynamic Range (DR)	86 dB	86 dB
Oversampling Ration (M)	192	792
Sampling Frequency	104 MHz	368 MHz
IF frequency	78 MHz	276.48 MHz
Signal Bandwidth	0.2 MHz	0.2 MHz

comparison between the Berger modulator and the new modulator.

The new modulator has an order equals to one and thus less integrators are needed. For each additional order we need an opamp to implement the integrator in addition to the digital switching circuitry. On the other hand since the sampling frequency of the new modulator is much higher than the Berger modulator, a sophisticated switching mechanism is needed. In addition increasing the sampling frequency will increase the dissipated power. However the overall modulator will consume less power since there is only one integrator in the system.

4. CONCLUSION

In this paper, a new technique for designing sigma delta modulators based on a weighted rectangular and trapezoidal integration was presented. The new modulator exhibits a controllable signal to noise ratio reaching better performance. The new modulator, like the conventional modulator, has stable poles and fast input tracking. The new modulator has a higher percentage increase in SNR as the oversampling decreases.

5. REFERENCES

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