

A Reconfigurable Sigma-Delta Modulator Architecture for Mobile Communications

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Abstract - The transition between the second and third generation of mobile communications services can be significantly facilitated by the design of reconfigurable mobile phones. This paper presents an architecture for dual standard receptors, which uses a reconfigurable sigma delta modulator for digitalization at intermediate frequency or at baseband. The proposed approach has been compared with the existing methods. High level simulations show its feasibility.

Keywords - Dual standard mobile phones, Dual standard Sigma-Delta modulators.

I. INTRODUCTION

The transition between the second and third generation of mobile communication services brings as a consequence the necessity of reconfigurable mobile phones. Even in the future, it is not expected that all suburban and rural areas are going to be covered by the new services of the third generation (3G) and then, the second generation (2G) is also going to be present demanding for receivers capable of handling standards coming from both systems. To date, some architectures for reconfigurable dual standard mobile phones (RDSMP) have been proposed [1,2,3]. Each of them shares in different ways the hardware resources at the purely analog radio frequency (RF) front end and at the digital signal processing and is aimed to manage the GSM and the UMTS systems. The interface between both sides has been reconfigurable sigma-delta modulators ($\Sigma\Delta$). This work aims to present an architecture for a RDSMP that uses the idea of reconfigurability in sigma-delta converters by going from a bandpass to a lowpass converter, digitizing so, intermediate frequency (IF) or baseband (BB) signals. Next, a brief review of the proposed approaches for RDSMP's is presented. Finally system-level simulation results for the proposed architecture are shown.

II. RDSMP ARCHITECTURES

One of the first approaches reported for the architecture of a RDSMP was presented in [1]. In that work the receiver had two separate RF paths as well as two different intermediate frequencies (see fig. 1).

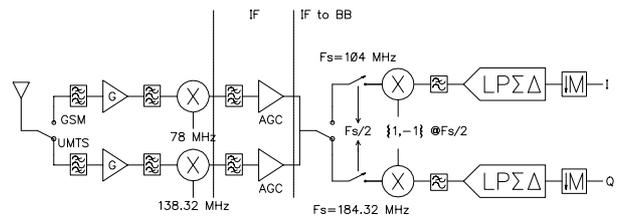


Fig 1. The dual standard receiver proposed in [1].

Dual mode operation was achieved by selecting each RF front end and reconfiguring the $\Sigma\Delta$'s at the IF-to-BB conversion stage in order to obtain the resolution imposed by each mode of operation. The reconfigurability of the $\Sigma\Delta$ is shown at the architectural level in fig. 2. The lowpass $\Sigma\Delta$ (LP $\Sigma\Delta$) of fig. 2 was clocked at 2 different frequencies (104 MHz for GSM and 184.32 MHz for UMTS) to obtain a signal to noise ratio (SNR) of 76 dB for GSM and 53 dB for UMTS. The cascade of integrators with feedforward was used with a zero at the border of the bandwidth for UMTS signals. This coefficient was inactive for GSM.

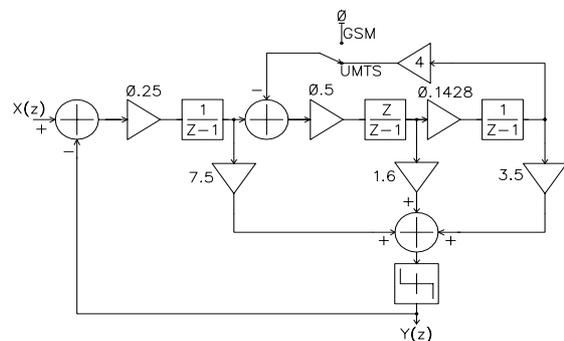


Fig. 2. The reconfigurable lowpass $\Sigma\Delta$ used in [1].

Although the reconfigurability at the $\Sigma\Delta$ is achieved easily, a lack of resource sharing in the analog RF front-end of this receiver is observed making their integration a non-optimal task.

To cope with this problem, Salo et. al. [2] proposed the RDSMP depicted in the figure 3. The approach used some shared building blocks in the RF front-end. Separate preselection and image rejection filters were required. Dual mode low noise amplifier (LNA) and dual mode mixer were used [4].

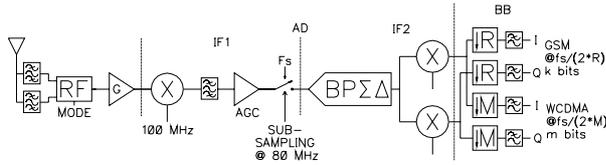


Fig. 3. A RDSMP with digitization at common IF.

A passive filter plays the role of anti-alias filter and channel selection filter for GSM and UMTS respectively. The usage of dual mode LNA and mixer enabled to operate at a single IF in both cases. A reconfigurable bandpass $\Sigma\Delta$ (BP $\Sigma\Delta$) was used for IF digitization. The architecture of that BP $\Sigma\Delta$ is drawn in the next figure.

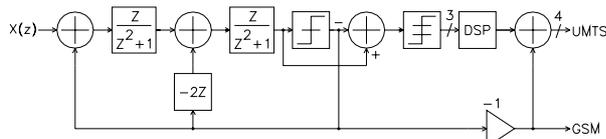


Fig. 4. Reconfigurable bandpass $\Sigma\Delta$.

Since the sampling frequency used was chosen to be a multiple of the UMTS chip rate, fractional decimation and interpolation are required in the GSM mode. In the UMTS mode, a 4 bit ADC together with a DSP was implemented to improve SNR which is degraded due to the fact that a lower oversampling ratio (M) was used while keeping the same noise shaping as in the GSM mode. Peak SNR values of 78 dB and 48 dB were obtained for the GSM and the UMTS standards respectively. Both the fractional decimation and interpolation needed in the GSM mode, as well as the 4 bit ADC plus DSP used in UMTS operation make the digital part of this receiver complicated, and even more the SNR of 48dB asks for high selectivity blocks in the RF front-end, which are difficult to design.

The RDSMP architecture proposed in [3] merges into one system a zero-IF receiver for the UMTS standard and a low IF receiver for GSM. In that paper, a novel variation of the IF signal processing was introduced for the GSM mode. The authors proposed to digitize only the I component of the IF signal centered at a half of the total bandwidth ($BW/2$). As the full BW is being digitized, it is possible to make the digitized signal once again complex in the digital domain by performing a Hilbert transformation. To compensate for the loss of image rejection, the usage of a passive polyphase filter (PPF) is necessary. This architecture is depicted in figure 5.

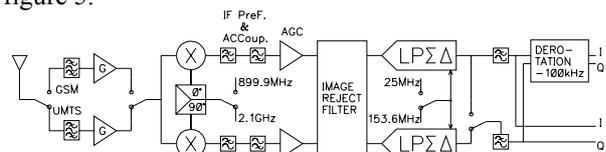


Fig. 5. Dual mode receiver proposed in [3].

For both BB and low-IF digitization, fourth order continuous time LP $\Sigma\Delta$'s with 1.5 bits quantization were used with clock rates of 25 MHz and 153.6 MHz for GSM and UMTS respectively. Operating in GSM mode, the whole RF Q path is not needed and one LP $\Sigma\Delta$ is inactive.

III. PROPOSED RDSMP ARCHITECTURE

The proposed architecture, shown below, is composed by a RF Front End and a reconfigurable $\Sigma\Delta$

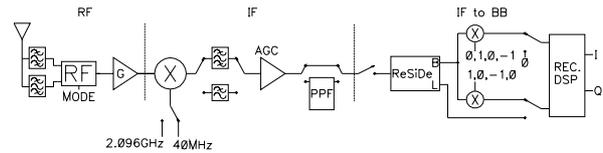


Fig. 6. Proposed RDSMP Architecture.

A. The RF Front-End

It uses separate preselection and image rejection filters but many building blocks are common. Dual mode LNA and mixer as in [2] are shared in both modes of operation. Two oscillators translate the input signal to a low IF of 1.92 MHz for UMTS and 40 MHz in GSM operation. The output of two IF filters is passed to a common AGC. The IF-to-BB conversion stage of this receiver is implemented with a reconfigurable $\Sigma\Delta$ (ReSiDe) that is going to present noise shaping for bandpass and lowpass signals. When operating in GSM mode, IF digitization is performed using the ReSiDe as 2nd order BP $\Sigma\Delta$ with noise shaping at $fs/4$, which facilitates the I and Q channel separation. In this case, the output of the AGC is connected directly to the ReSiDe. Operation in the UMTS mode uses the concept described in [3], here the output signal of the AGC is passed through a PPF before its digitalization at the proposed ReSiDe, that is going to work as a wideband 4th LP $\Sigma\Delta$.

B. ReSiDe

Because of the advantages described in [5], a cascade of resonators with feedforward was chosen as basis for the architectural design of the proposed dual standard converter. Fig. 7 shows the 4th order structure of this architecture. It consists of two resonators constructed as lossless discrete integrators, that allow to put zeros in the noise transfer function (NTF) and are set by coefficients $g1$ and $g2$. Coefficients bi fix the poles of the same function. Operation in the GSM mode, requires bandpass digitalization of a narrow band signal, in this case, the $\Sigma\Delta$ is going to be working with the next set of scaled coefficients:

$$\begin{aligned}
 b1 &= 0.0; & c1 &= 0.1262; & g1 &= -1.1110; \\
 b2 &= -0.3334; & c2 &= 1.8000; & g2 &= -1.6753; \\
 b3 &= -1.2339; & c3 &= 0.2702; & & \\
 b4 &= -1.0335; & c4 &= 1.1940; & &
 \end{aligned}$$

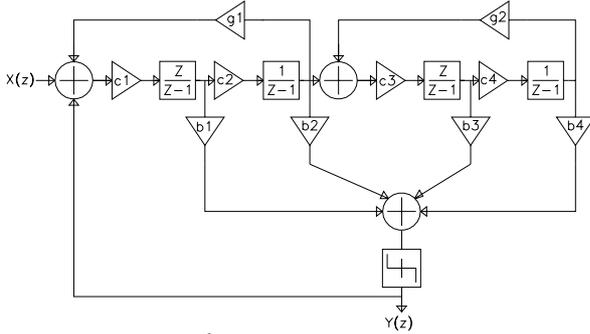


Fig. 7. A 4th order cascade of resonators with feedforward.

This architecture has the property of having a signal transfer function that is complementary to the *NTF*. The values of the coefficients were chosen to implement the following function: $NTF = (1+z^{-2})^2$ which has been extensively studied. It is well known that, if the only noise source in the $\Sigma\Delta M$ is due to quantization the SNR is given by:

$$SNR = \frac{30A^2M^5}{\pi^4\Delta^2} \quad (9)$$

Where A is the amplitude of the input sinusoid and Δ the quantization step. The proposed IF of 40 MHz asks for a f_s of 160 MHz, which produces an $M=200$ for GSM signals. With $\Delta=1$ and $A=0.5$ a SNR of 96 dB would be produced, that is well suited for GSM.

The UMTS operation mode requires digitalization of a lowpass signal with a BW of almost 4MHz. Previous work [6] showed that a stabilized 4th order LP $\Sigma\Delta M$ with zeros at certain optimal positions of the BW could reach a SNR of 60 dB with an M around 16. Using the method described in [7], the following 4th order inverse Chebyshev *NTF* was designed using the cheby2 function of MATLAB, where two zeros were moved from the origin and put at the middle and end of the BW using an $M=20$.

$$NTF = \frac{1 - 3.9753z^{-1} + 5.9508z^{-2} - 3.9753z^{-3} + z^{-4}}{1 - 3.0905z^{-1} + 3.6776z^{-2} - 1.9844z^{-3} + 0.4083z^{-4}} \quad (10)$$

The set of scaled coefficients given below implement the desired *NTF*:

$$\begin{aligned} b1 &= 1.2781; & c1 &= 0.1748; & g1 &= -0.0407; \\ b2 &= 0.8141; & c2 &= 0.5200; & g2 &= -0.0256; \\ b3 &= 0.7548; & c3 &= 0.3124; & & \\ b4 &= 0.6186; & c4 &= 0.1408; & & \end{aligned}$$

High level simulations performed with MIDAS [8] show that a peak SNR of 65 dB could be reached after filtering and decimation (fig. 8), this value helps to reduce the selectivity requirements of the RF chain in UMTS mode. In principle, the clock rates supported for each mode of operation should be very similar. If the

UMTS BW is approximated to be 4 MHz, an M of 20 produces a $f_s=160$ MHz and the same clock frequency could be used as in the bandpass mode.

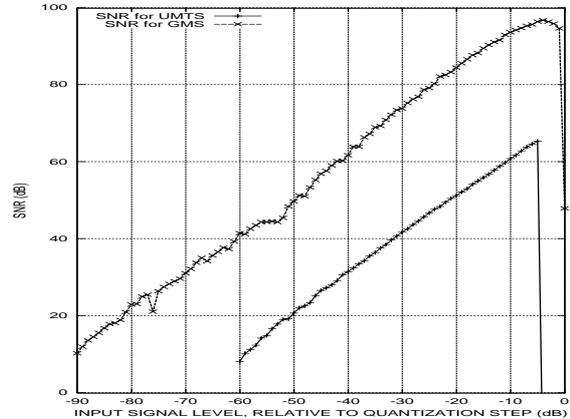


Fig. 8. SNR vs. input signal level for both modes of operation.

Circuit implementation considerations. The target technology of this design is a 0.35 μ m CMOS technology. Switched capacitor (SC) techniques are going to be used because they facilitate the reconfigurability. The sensitivity of both *NTF*'s regarding the following SC implementation impairments has been examined by means of high level simulations with MIDAS: capacitor mismatch, operational amplifier (op. amp.) finite voltage gain (A_v), op. amp. finite slew rate (SR) and op. amp non zero settling time (T_s).

Capacitor Mismatch. Data from the manufacturer report matching of capacitors with standard deviation (σ) of 1.2%. Random numbers with a gaussian distribution and the given σ were generated around one. These numbers were used to individually perturb the coefficients of each *NTF* and to run 1000 Monte-Carlo simulations in which the peak SNR was taken as output parameter. The resulting SNR had the statistical characteristics shown in the histograms in fig. 9. In accordance with those histograms the SNR has the following characteristics for each case:

Lowpass:	Bandpass:
$SNR(min)=64.6$ dB	$SNR(min)=60.3$ dB
$SNR(max)=65.9$ dB	$SNR(max)=99.9$ dB
$SNR(mean)=65.3$ dB	$SNR(mean)=81.3$ dB
$\sigma = 0.214$	$\sigma = 8.15$

The σ obtained for the bandpass *NTF* shows a bigger sensitivity to capacitor mismatch, however the mean stills delivering a SNR good enough for GSM signals, while in the lowpass case a very good robustness is observed.

Op. Amp. non idealities: The functions included in MIDAS allow to develop easily models of the already mentioned op. amp impairments. Simulations showing the degradation of the peak SNR due to different values

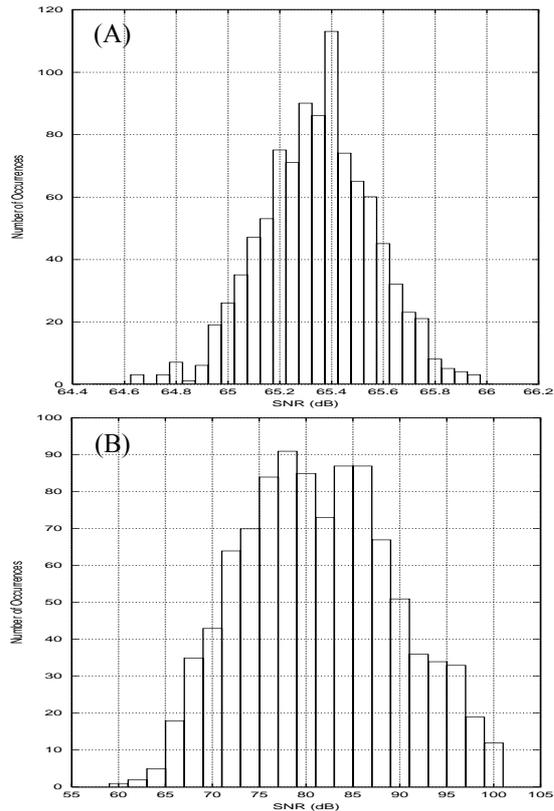


Fig. 9. Histograms showing Monte-Carlo simulation results (A) Lowpass NTF (B) Bandpass NTF

of A_v , SR and T_s are shown in figure 10 for the chosen architecture when it is used to synthesize both NTF's. These graphs provide useful information for the circuit design of the $\Sigma\Delta$.

IV. CONCLUSIONS

System design and circuit considerations for the implementation of a reconfigurable lowpass/bandpass $\Sigma\Delta$ have been presented. The proposed converter architecture is well suited for applications in dual standard mobile phones. A possible RDSMP that uses the proposed system was introduced and compared with previous approaches. The conducted comparison shows that the proposed solution represents an interesting alternative to reported approaches.

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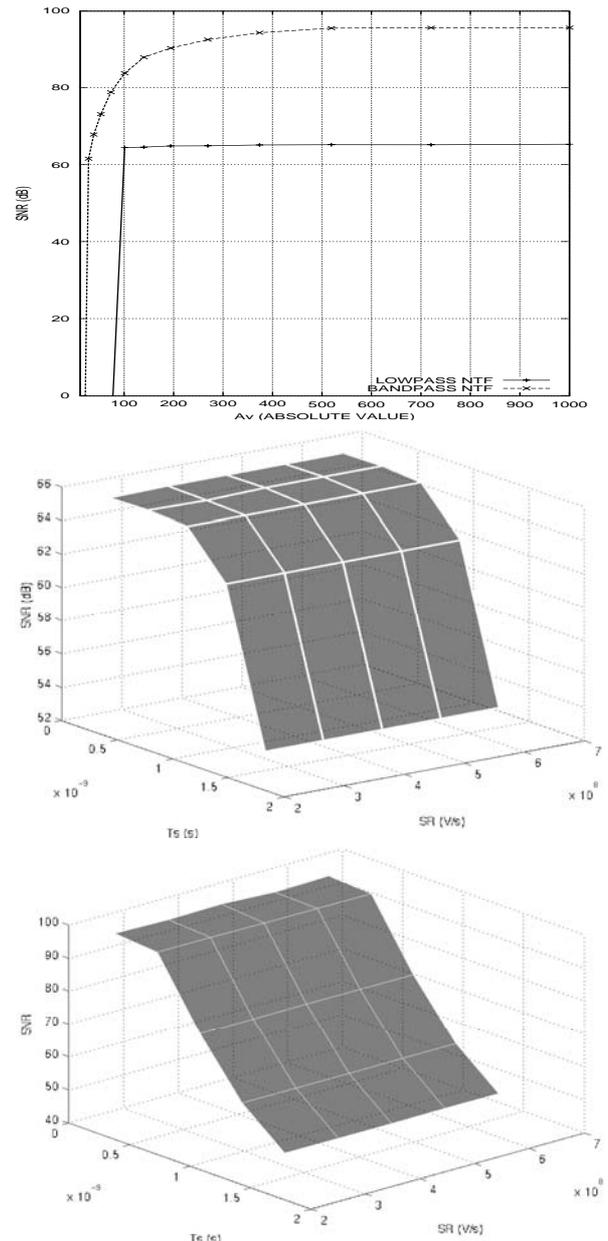


Fig. 10. SNR degradation due to non idealities: finite A_v , SR and T_s for both NTF's.

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