Investigation of Direct Delta Sigma Receiver for Modern Cellular Systems

S. Manjula1*, M. Malleswari2, A. Asha3
1Department of Electronics and Communication Engineering, Rajalakshmi Institute of Technology, Chennai, TN, India
2Department of Information Technology, Vel Tech High Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, TN, India
3Department of Electronics and Communication Engineering, Rajalakshmi Engineering College, Chennai, TN, India

*Email: manjulasankar@gmail.com

Abstract:
This paper presents the significance of Direct Delta Sigma Receiver (DDSR) in modern cellular communication systems. The development of 4G/5G technologies such as LTE and WiMax has increased the need for digital technology and new solutions for cellular systems. Due to the demand of digitalization in modern cellular applications which leads to minimize the analog circuits, DDSR is introduced and becomes more popular than other conventional receivers. DDSR is the combination of front end of direct conversion receiver and Delta Sigma Modulator (DSM). The importance and structure of DDSR are studied. In DDSR, quantization noise shaping with filtering can be provided by the feedback loop. The filter coefficients are mapped to the properties of RF circuits at the front end is more challenging and difficult task. Optimization of filter coefficients plays an important role in DDSR. In future, optimization methods and algorithms can be efficiently used to optimize filter coefficients in DDSR.

Keywords: DDSR, direct conversion, filter, DSM and LNA

1. Introduction:
Due to the tremendous development in wireless communication systems, the user can communicate from remote operated areas using wireless communication devices with the wireless technologies such as Mobile phones, Bluetooth, etc [1]. Due to the increasing needs of broadband mobile services, there is a tremendous improvement in generation of wireless technologies like 3G, 4G and 5G [2]. LTE (Long Term Evolution) and Wimax are the popular 4G technologies which support 3GPP (Third Generation Partnership Project) for achieving high speed mobile access [3]. To provide faster and more reliable mobile access than LTE, LTE-A (LTE-Advanced) is built. The 4G LTE-A system offers wide bandwidth, a good user access with efficient resource management and utilization [4]. WiMax is the technology standardized by IEEE 802.16. Wimax technology supports frequency reuse, multicast and broadcast service [5]. When comparing LTE and WiMax, LTE is much popular and widespread than WiMax. The 4G technologies are increasing the demand of wireless CMOS transceivers for cellular applications.

Various RF Receiver architectures are widely used for wireless communication systems. The receiver architectures are 1. Heterodyne receiver 2. Homodyne or direct conversion receiver 3. Low-IF receiver [6]. Recently, the digitalization of RF receiver has received a lot of attraction. For modern cellular
communication especially 4G technologies, conventional architectures are not suitable. In direct RF-to-digital conversion, delta sigma modulator plays a very important role. A prior advantage of \( \Sigma \Delta \) modulation is that the null noise with the signal passband. For this reason, direct delta sigma receiver is the most suitable for 4G and next generation technologies. In this paper, the design, importance and drawbacks of delta sigma receiver is reviewed. Also, the block diagram of DDSR is studied and filter coefficients of DDSR are studied. The analysis of modeling and optimization of filter coefficients are reviewed.

2. Receiver architectures

For portable wireless devices, the most commonly used RF receiver is the direct conversion receiver [7]. The direct conversion receiver architecture is shown in Figure 1.

![Figure 1. Direct Conversion Receiver Architecture](image)

In this receiver architecture, the RF signal received from an antenna amplified by using low noise amplifier (LNA) and down converted to baseband signal directly. The baseband signal is further amplified by baseband amplifier and then filtered. Finally, analog to digital converter is used to convert into digital signal. Direct conversion receiver architecture is not well suitable for current and future generation wireless technologies. Since, the 4G/LTE technology supports MIMO and carrier aggregation, the need of multimode flexible receiver is increased. Since LTE/ LTE–A requires more linearity, digital based receiver is introduced. The digital based receiver architecture reduces the analog circuits for implementing baseband stages compatible with CMOS technology. The direct delta sigma receiver is developed from the concept of delta sigma modulator and the front end of direct conversion receiver. The concept of DDSR is the basis of delta sigma modulator (DSM) [8]. The general DSM block diagram is shown in Figure 2.

![Figure 2. Basic Delta Sigma Modulator](image)

It is the first-order \( \Delta \Sigma \) modulator. The feedback loop computes the difference between the input and output signals. The architecture of Direct Delta Sigma Receiver is shown in Figure 3.
In direct delta sigma receiver, the first integrator stage consists of two gain stages which are low noise amplifier and Gm stage with the delta sigma modulator (DSM). The DSM loop filter is involved in quantization noise shaping and channel filtering. Quadrature down-conversion mixer is directly downconverted to baseband signal. The baseband signal is directly given to the baseband modulator and integrator stages. The output from the baseband stage is fed back to RF front end stages for improving noise shaping and filtering.

3. Analysis of Direct Delta Sigma Receiver:

Now-a-days, DDSR has a potential solution for supporting multimode and frequency agile. DDSR has an important advantage of reducing the number of baseband stages by directly connecting the front end and ADC to reduce the area and power consumption. However, modern cellular receiver is affected by out of band interference signals. Out-of-band linearity is a major challenge in cellular systems. Filtering of out-of-band signals is more required at the RF stages in DDSR. Filtering at the RF stages is more complicated. In DDSR, the feedback loop is established to connect the baseband and the RF stages. Many papers are discussed about filter design, modeling and optimization of filter coefficients at the RF stage for improving out of band linearity [9-11].

Kimmo Koli et al., [9] developed the prototype of 4th order continuous time delta sigma modulator which is having number of integrators connected in cascade with feedback loops and a one-bit quantizer. The loop filter coefficients are optimized for maximizing SNDR. In DDSR, the total transfer function of DDSR is more important to calculate gain, filtering and noise shaping. There are two important transfer functions Signal Transfer Function (STF) and Noise Transfer Function (NTF). NTF and STF can be calculated by,

\[ NTF = \frac{1}{1-L_1} \]  
\[ STF = \frac{L_0}{1-L_1} \]  

where L0 and L1 are signal path and feedback path TF of the loop filter. In [10], transfer function of each block such as Gm-C N-path filter, Baseband DSM, RF to Baseband, Baseband to RF and FIRDAC calculated. The overall transfer function estimated by applying transfer function of each block.

For DDSR modeling, CT and DT design approaches are used. Kim B. Östman et al., [11] proposed the alternative continuous time DDSR. The modeling of DDSR provided the equations of STF and NTF. Also, the new equations are derived for mapping of filter coefficients to the RF front end blocks. RF
blocks have to be modeled. LNA and N-path GmC filer are modeled as first integrator for obtaining the functions of integration. These integration functions are used to map the coefficients to RF block properties.

4. Simulation Tool for DDSR

The models are verified by MATLAB. In MATLAB, Delta Sigma Toolbox is very efficient for optimization of DDSR. It involves many functions. It directly calculates NTF, STF, SNDR, dynamic range scaling, SNR estimation and more.

DSM needs transient simulation. The front end of receiver consists of LNA and mixer which require S-parameter and harmonic balance simulations. Due to the involvement of DSM and front end blocks in DDSR, the simulation of DDSR is a major problem. Minh Tien Nguyen et al., [10] simulated the DDSR using transient approach and discussed some of the simulation issues in DDSR. DDSR simulation consumes more time since it consists of many RF feedbacks and switched capacitor circuits. To reduce transient time of DDSR, real time values for model parameters such as rise/ fall time, transconductance gain, etc were used. During the simulation, sweep simulation step of samples was chosen as maximum. For careful choosing of maximum step parameter, DDSR simulation achieved good tradeoff between accuracy and simulation time. The noise and linearity analysis of front end blocks of DDSR is very important. This can be done by using noise and nonlinearity simulation.

In DDSR, filter coefficient optimization is very important role for matching with the RF stage properties. For optimization of filter, many algorithms and methods are presented [12-15]. New quantization algorithm was developed for optimization of filter coefficients [12]. In [13], FIR filter coefficients were optimized and improved using differential evolution algorithm. An efficient optimization algorithm can be used to optimize the filter coefficients in DDSR. In [15], S-plane model was created using transfer functions for analyzing and optimizing the filter coefficients.

5. Conclusion:

In this paper, DDSR and its related works are reviewed. DDSR is more suitable for modern cellular applications. The mapping of filter coefficients to the RF stages is a major challenge in DDSR. The optimization of filter coefficients is more important for improving out-of-band linearity. The transfer functions such as STF and NTF are discussed which are more important for calculating filter coefficients. From this study, the optimization of filter coefficients plays a primary role in DDSR. The use of optimization algorithms can be more efficient for optimizing filter coefficients.

References

[1]. Candice King 2015 Wireless Communication: A Basic Tutorial on Radio Technology IEEE Industry Applications Magazine, 21, 14 – 18.
[2]. Ioannis N. Kriaras, Andre W. Jarvis, Vincent E. Phillips and Derek J. Richards 1997 Third-Generation Mobile Network Architectures For The Universal Mobile Telecommunications System (UMTS). Bell Labs Technical Journal, 2, 99-117.
[3]. Sricharan M S 2011 Tutorial: Towards 4G wireless systems (WIMAX &LTE) BR (4GWS). Int. Conf. on Recent Trends in Information Technology (ICRTIT).
[4]. Janry Budomo, Iftekhar Ahmad, Daryoush Habibi and Eric Dines 2017 4G LTE-A Systems at Vehicular Speeds: Performance Evaluation. Int. Conf. on Information Networking (ICOIN).
[5]. More S and Mishra D K 2012 4G Revolution: WiMAX technology, Third Asian Himalayas Int.Conf on Internet (AH-ICI).
[6]. Crols J and Steyaert MSJ 1997 CMOS Wireless Transceiver Design, Kluwer, Boston.
[7]. Behzad Razavi 1997 Design Considerations for Direct Conversion Receivers. *IEEE Trans. on Circuits and Systems II: Analog and Digital Signal Processing* 44, 428 – 435.

[8]. Behzad Razavi 2016 The Delta-Sigma Modulator *IEEE Solid-State Circuits Magazine* 8,10 – 15.

[9]. Kimmo Koli, Sami Kallioinen, Jarkko Jussila, Pete Sivonen, and Aarno Pärsinnen 2010 A 900-MHz Direct Delta-Sigma Receiver in 65-nm CMOS. *IEEE J. Solid-State Circuits* 45, 2807-2818.

[10]. Minh Tien Nguyen, Chadi Jabbour, Cyrius Ouffoue, Rayan Mina, Florent Sibille, Patrick Loumeau, Pascal Triaire and Van Tam Nguyen 2013 Direct Delta-Sigma Receiver: Analysis, Modelization and Simulation. *IEEE Int. Symp on Circuits and Systems (ISCAS2013)*, p 1035 – 1038.

[11]. Kim B. Östman, Mikko Englund, Olli Viitala, Kari Stadius, Kimmo Koli and Jussi Ryynanen 2015 Next-Generation RF Front-End Design Methods for Direct ΔΣ Receivers. *IEEE J. on Emerging and Selected Topics in Circuits and Systems*.5, 514-524.

[12]. Seyed Mohammad Ali Zeinolabedin and Nader Karimi 2012 A new quantization algorithm for FIR filters coefficients. *20th Iranian Conf on Electrical Engineering (ICEE)*.

[13]. Srinivasa Reddy Kothaa and Subhendu Kumar Sahooa 2015 An approach for FIR filter coefficient optimization using differential evolution algorithm. *Int. J. of Electronics and Communications (AEÜ)*.69,101-108.

[14]. Sangeeta Mondal, S. P. Ghoshal, Rajib Kar and Durbadal Mandal 2012 Novel Particle Swarm Optimization for Low Pass FIR Filter Design *WSEAS Trans. on Signal Processing*.8,111-120.

[15]. Mikko Englund, Olli Viitala, Jussi Ryynanen and Kimmo Koli 2012 N-path gmC Filter Modeling and Analysis for Direct Delta-Sigma Receiver. *10th IEEE Int. NEWCAS 2012 Conf*. p 277-280