Design of High Linearity CMOS OTA Based Bandpass Filter for Bluetooth Receiver

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Abstract— **In the Current trend, mobile devices integrate Bluetooth and many other wireless IC sub-blocks inside a single IC which require low voltage and low power for longer battery life. So there is a need of low voltage low power and high linearity of on-chip filter to operate in desired frequency band. In this paper focuses on Bluetooth receiver architecture which includes integrated bandpass OTA-C filter for input signal filtering. In this proposed design biquad bandpass filter is designed for the Bluetooth application using CMOS 45nm technology with 0.7V supply voltage. The power dissipation of the proposed filter design is very low 341μw with output noise is 55.20 nV/$\sqrt{Hz}$.**

Keywords— BPF, CMOS, Low Power, Bluetooth, OTA, GFSK, SNR, BER

I. Introduction

In the Current trend, mobile devices integrate Bluetooth and many other wireless IC sub-blocks inside a single IC which require low voltage and low power for longer battery life. So there is a need of low voltage low power and high linearity of on-chip filter to operate in desired frequency band. Bluetooth standard is now works as short distance communication link between the devices. Bluetooth receivers works in 2.4 GHz ISM band which is a non-licensed band available for the use industrial, scientific and medical applications. The Bluetooth is designed in order to replace the extra cable used for short distance communication which is near about 10m. The low cost, low power and robustness of the Bluetooth makes it ideal for the use in various applications such as mobile phone, medical service, home entertainment products and computers.

Various versions of Bluetooth are available now but the classic version of the Bluetooth is most famous among them since it provides a better throughput 0.7-2.1Mbps as compared to Bluetooth v4.0 which provides only 0.3 Mbps. Bluetooth devices use 2.4-2.483GHz unlicensed ISM band [1]. It is divided into 78 channels with channel spacing of 1 MHz

$$f = 2402 + k \text{ MHz};\ k = 0 \ldots 78$$

In order to comply with out-of-band regulation a lower guard band of 2 MHz and Upper guard band of 3.5 MHz is kept. A Frequency hopping spread spectrum technique is used to combat the interferences and fading. A GFSK with a bandwidth-bit time period BT=0.5 and modulation index between 0.28 and 0.35 is used. A binary one is represented by a positive frequency deviation, while binary zero is represented by a negative frequency deviation. A symbol rate of 1 Ms/s is used. For full duplex transmission, a Time Division duplex scheme is used. Receiver's performance is often measured in terms of its sensitivity although the performance of a wireless communication system is often specified in terms of BER [1] which is very impractical for the receiver front-end design. As a receiver front end can only be evaluated by adding unwanted signals, such as noise, image signals and inter modulation signals, to the wanted signal, the performance can therefore be translated into the specification of SNR. The sensitivity of a receiver is defined as minimum signal power at the input of the receiver which gives the required SNR at the output of the receiver.According to the Bluetooth specification, a receiver needs to have a sensitivity of -70dBm or below. The interference performance in the co channel and adjacent 1 MHz and 2 MHz will be measured with the desired signal 10 dB above the reference sensitivity level. Until recently, radio frequency integrated circuits were implemented in the GaAs and SiGe technologies due to their relatively high unit gain cutoff frequency fT. But due to recent advances in CMOS technology, the minimum feature size of the CMOS device is decreasing and as a result, the fT of the transistors continues to improve and has reached the point where CMT fT is comparable to the GaAs processes and SiGe. With a deep submicrometer CMOS device, you could achieve fT greater than 30 GHz and a minimum amount of noise less than 0.5 dB. Due to these good RF characteristics and other advantages such as low cost and the ability to integrate RF, IF and transceiver baseband blocks into a single substrate, CMOS is becoming the preferred technology for new low cost wireless communications applications such as wireless LAN, Bluetooth, etc.

TABLE 1 : BLUETOOTH SPECIFICATION SUMMARY

PARAMETER	VALUE	COMMENT
Connection		
Duplex	TDD	
Access	TDMA	
TDD guard time	220 /us	
Frequency		
Channel spacing	1 MHz	
Accuracy	±75 kHz 400 Hz/µs	*initial center frequency* *Max. drift rate*
Modulation		
Type	GFSK (BT=0.5)	
Freq. deviation	± 140-175 kHz	Mod. Index 0.28... 0.35
Burst bit rate	1 Mbit/s	
Minimum freq. deviation	115 kHz	
Receiver		
Sensitivity	-70 dBm	BER = 0.1 % (71µs rms on 50 Ω)
Max. input level	-20 dBm	(23 mV rms on 50 Ω)
Noise figure	25 dB	SNR dem=19
Blocking *(S=-67 dBm)*	-27 dBm -10 dBm	2.0-2.399 GHz 2.498-3.0 GHz 30-2000 MHz 3.0-12.75 GHz
Image rejection	20 dB	in-band
Spurious emission	-57 dBm -47 dBm	30-1000 MHz 1-12.75 GHz (out-of-band)

II. BIQUAD BANDPASS FILTER DESIGN

Biquad filter is a 2nd order filter because its transfer function is ratio of two quadratic polynomial a sfg (signal flow graph) block diagram of biquadratic 2nd order filter is shown in fig1.

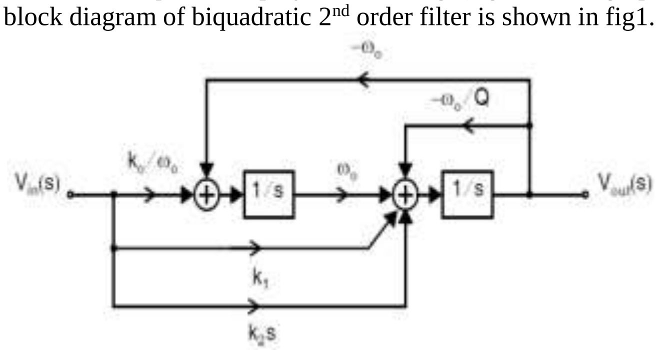

Figure 1 : Signal flow block diagram of biquad transfer function

The transfer function for biquad filter is given by

$$H(s) = \frac{s^2 k_2 + k_1 s + k_0}{s^2 + \left(\frac{\omega_o}{Q}\right) s + {\omega_o}^2} \qquad \text{\_\_\_\_\_\_\_\_\_\_ (1)}$$

The transfer function of equ (1) is a two pole system which requires two integrators required to realize the poles. To have the stability (ω_o/Q) must be positive which implies that one of the two integrator must have positive feedback around it making it lossy when Q<0.5 two poles are real and when Q>0.5 poles form complex conjugate pair. Fig x55 can be used to realize low-pass, high-pass and band-pass response. Since we want to realize a bandpass filter then the coefficients transfer function $k_1 = k_0 = 0$. This result in

$$\mathrm{H(s)} = \frac{\mathrm{k_1 s}}{s^2 + \left(\frac{\omega_o}{Q}\right) s + {\omega_o}^2} \qquad \text{\_\_\_\_\_\_\_\_\_\_(2)}$$

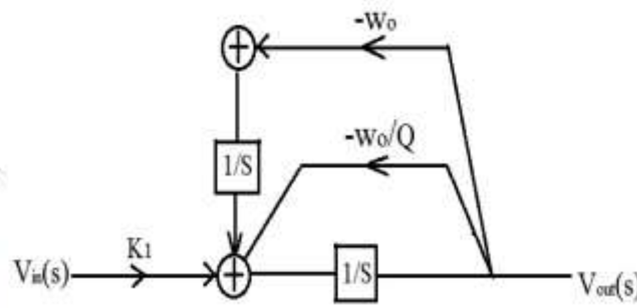

Figure 2 : Block diagram of transfer function modified for bandpass filters

The block diagram in fig 2 can be implemented through active component i.e. by Gm-C integrator blocks. In order to achieve bandpass filtering we require a structure made of Gm and C active components as shown in fig 3.

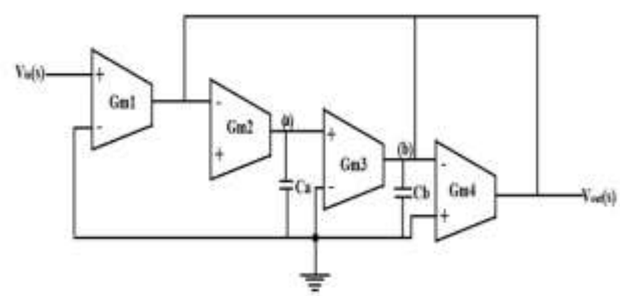

Figure 3 : Single ended bandpass filter structure

Analysis for single ended configuration of bandpass filter must be first carried out so that the overall transfer function can be obtained in terms of voltage at the nodes.

Σ i=0 at node a,

$$s.C_a.V_a(s) - G_{m2} V_{out}(s) = 0 \qquad \text{\_\_\_\_\_\_\_\_ (3)}$$

$$V_a(s) = \frac{G_{m2}}{s.C_a} V_{out}(s) \qquad \text{\_\_\_\_\_\_\_\_ (4)}$$

Again Σ i=0 at output results

$$G_{m1}.V_{in}(s) + G_{m3} V_a(s) + s.C_b.V_{out}(s) + G_{m4} V_{out}(s) = 0 \qquad \text{\_\_\_\_\_\_\_\_ (5)}$$

Solving equ (4) and (5) yields

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{s.G_{m1}/C_b}{s^2+s.\frac{G_{m4}}{C_b}+\frac{G_{m3}.G_{m12}}{C_b.C_a}} \qquad (6)$$

Comparing equ (2) and (6) we obtain

$$K_1 = \frac{G_{m1}}{C_b} \qquad (7)$$

$$\frac{\omega_o}{Q} = \frac{G_{m4}}{C_b} \qquad (8)$$

And

$$\omega_o{}^2 = \frac{G_{m2}.G_{m3}}{C_b.C_a} \qquad (9)$$

Thus,

$$Q = \frac{C_b}{G_{m4}}.\sqrt{\frac{G_{m2}.G_{m3}}{C_b.C_a}} \qquad (10)$$

The overall bandpass filter structure shown in fig 3 is a single ended form; its differential structure is designed and simulated in LTspice4 environment with 45nm CMOS technology. The fully differential structure of the filter shown in fig 3 is shown in fig 4. In order to tune the transconductance of the filter different power sources has been used in the design. So that the overall response required for the filter for the application of Bluetooth can be achieved.

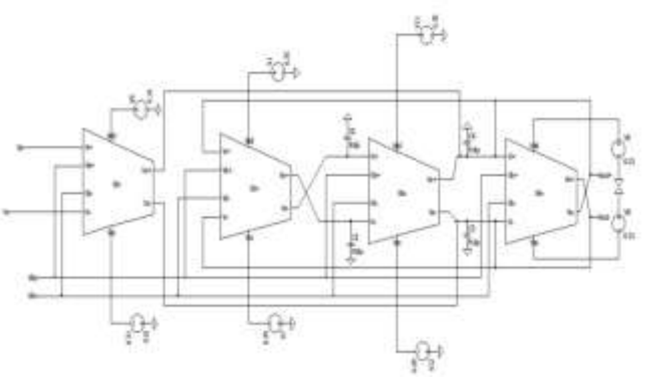

Figure 4 : Biquad Bandpass Structure of the Filter

The fully differential structure of the biquad bandpass filter is shown. This filter has four transconductance block for which analysis and equations has been obtained previously. The transconductance and capacitor values to obtain the Bluetooth performance is summarized in table 2.

Table 4.1:- Various parameter values required to generate bandpass filter response

PARAMETER	VALUES
Gm1	62 µS
Gm2	166 µS
Gm3	166 µS
Gm4	62 µS
Ca	9.8pF
Cb	9.8pF
Input referred noise	350 nV/$\sqrt{Hz}$
Power dissipation	341µW
Output noise	55.20 nV/$\sqrt{Hz}$
In band Group delay	94 ns

The simulated response of the filter shows that the center frequency for the filter is 3MHz with very low power dissipation of 341µW only with maximum yet very low power source of ±0.35 V. The AC response of the filter is shown in fig 5.

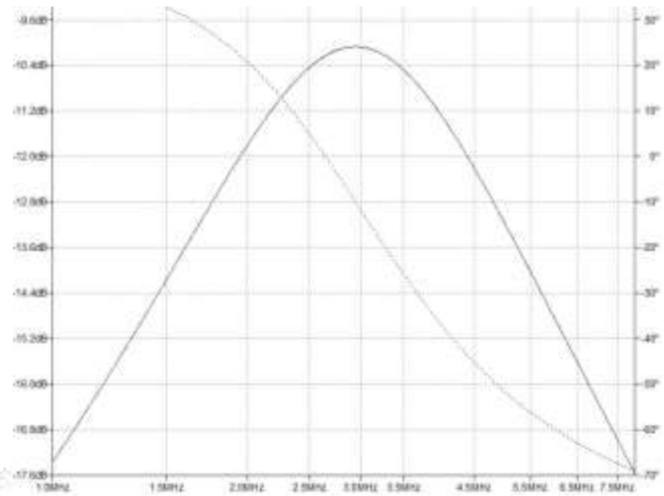

Figure 5 : Gain for the Biquad Filter w.r.t Frequency

The filter achieves a gain of -10 dB at 3MHz with a bandwidth of 1.2MHz, the attenuation requirement of more than 20dB at f_c±1MHz is not fulfilled thus the filter performance is not up to the mark. Generally a biquad or a second order filter is not enough to fulfill the requirement for attenuation in the sibe bands. Thus, a filter of higher order with Butterworth or chebychev configuration is used or the cascaded design of both the configuration can be used as used in [8 & 38]. As the design presented in [38 and 33] the order of the filter is 14 and 12 respectively, the use of higher order filter satisfies the bandwidth and attenuation requirement but have larger current requirement and result in larger power dissipation. In this thesis, considering the above mentioned points a complex filter with an order 3 and very low voltage design has been presented.

III. CONCLUSION

In this proposed design OTA-C based biquad bandpass filter is designed for the Bluetooth receiver. The proposed design is implemented using the CMOS 45nm technology with 0.7V supply voltage. The power consumption of the proposed design is very low then the previous work which 341µW and the linearity of the filter is also very high. The input referred noise of the proposed filter design is 350 nV/$\sqrt{Hz}$ and the output noise is 55.20 nV/$\sqrt{Hz}$. The band group delay is 95nS.

REFERENCE

[1]. Specifications of the Bluetooth System, Version 1.0 B, Overland Park, KS, Bluetooth SIG, 1999.

[2]. Tamer farouk, Ahmed Nader mohieldin, Ahmed hussain khalil "A low voltage low power CMOS fully differential linear

transconductor with mobility reduction compensation" microelectronics journal, vol-43,pp - 69-76,2012.

[3]. D.A Jones and K.W. Martin "Analog integrated circuit design" John Wiley and sons, 2nd Ed, 2012.

[4]. K. Philips, "ADC for Bluetooth Receivers, "A 4.4mW 76dB Complex Σ-δ ADC for Bluetooth Receivers,"" in IEEE Int. Solid State Circuits Conf., San Francisco, Feb. 2003.

[5]. B. Razavi, "Architectures and Circuits for RF CMOS receivers," in Proc. IEEE Custom Integrated Circuits Conf., pp. 393-400, May 1998.

[6]. Randall L. Geiger and Edgar Sânchez-Sinencio "ACTIVE FILTER DESIGN USING OPERATIONAL TRANSCONDUCTANCE AMPLIFIERS: A TUTORIAL" IEEE CIRCUITS AND DEVICES 8755-3996/85/0300 1985.

[7]. Jaime E. Kardontchik "INTRODUCTION TO THE DESIGN OF TRANS CONDUCTOR-CAPACITOR FILTERS" Raytheon Company, Mountain View, CA ISBN 978-1-4615-3630-7 (eBook) DOI 10.1007/978-1-4615-3630-7.

[8]. Tony Chan Carusone, David A. Johns, Kenneth W. Martin. "ANALOG INTEGRATED CIRCUIT DESIGN",John Wiley & Sons, Inc, 2012.

[9]. A.hassan, K sharaf, H. El-Ghitani and H.F Ragai "THE DESIGN AND IMPLEMENTATION OF BANDPASS GM-C FILTER FOR BLUETOOTH" IEEE circuit and system 2002.

[10]. Daniele Grasso, Giuseppe Avellone "A NEW APPROACH FOR MULTISTAGE ANALOG COMPLEX FILTER DESIGN" ICWMC 2013: The Ninth International Conference on Wireless and Mobile Communications,2013.

[11]. C. Laoudias, C. Psychalinos, "Low-Voltage Bluetooth/ZigBee Complex Filter Using Current Mirrors," Proc. IEEE ISCAS, Paris, France, pp. 1268-1271, May 2010.

[12]. B. Guthrie, J. Hughes, T. Sayers, A. Spencer, "A CMOS Gyrator Low-IF Filter for a Dual-Mode Bluetooth/ZigBee Transceiver," IEEE Journal of Solid-State Circuits, vol. ED-40, no. 9, pp. 1872–1879, Sept. 2005.

[13]. C. Laoudias, C. Psychalinos, "1.5-V Complex Filters Using Current Mirrors," IEEE Trans. Circuits and Systems-II, vol. ED-58, no. 9, Sept. 2011.