A Low Power and High Bandwidth Gm-C Anti Aliasing Filter for DAB Receivers

Mohammad Mehdi Farhad, Sattar Mirzakuchaki

***Abstract*- This paper describes a low-voltage and low-power Gm-C low pass filter. The low-pass filter that precedes the A/D converter is called anti-aliasing filter.**

In the analog signal processing, the anti-aliasing filter would be one of the most important circuits in the transceiver architecture. This filter is located in the analog front-end circuits of DAB receivers.

The 4th – order butterworth Gm-C low-pass filter using the proposed transconductore is simulated in a 0.18µm CMOS process. In this project, we have minimized the power consumption and maximized the cut-off frequency of the anti aliasing filter. The circuit consumed 848.17µwatt through a 1.8V power supply with a cut off frequency 80MHZ.

***Index Terms* - Anti Aliasing Filter, Digital audio broadcasting, gm-c filter, Transconductance.**

I. INTRODUCTION

Nowadays, digital technology can increase the quality of sound produced with conventional techniques by 50%, but this increase will not reach 100% until the broadcast is also digital.

Broadcasting with analog technology suffers signal degradation problems, accumulating noise and distortions during each one of the phases that it goes through. On the other hand, digital information is easily transportable and storable, also using up less space.

This characteristic allows receivers to act like small computer that can process the information, and this not only affects the sound but all the data that the radio broadcaster wants to send in order to give added value to the service offered.

In contrast to AM and FM radio, the new digital radio broadcast (DRB) service provides much better quality of services to fixed, portable , and vehicular receivers.

Digital Audio Broadcasting is a method for the digital transmission of radio signals. DAB is the transmission technology of the future and will replace FM and AM radio in the medium to long term. [13]

The DAB receiver sales and growth of the various digital platforms are shown in Fig.1 and Fig. 2.

Manuscript received March 4, 2010.

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The key features of the digital audio broadcasting system are summarized:

- Quality of service
- Superior sound quality
- Usability
- Perfect reception conditions
- Wide range of value-added services
- Typical audio broadcasting (main service)
- Public information (news, weather reports etc)
- Electronic newspapers
- Electronic mailbox
- Universal system layout
- Standardization
- Unique system design
- Wide choice of receivers
- Transmission efficiency
- Lower transmission costs for transmitter network provides
- Lower transmission costs for broadcasters.

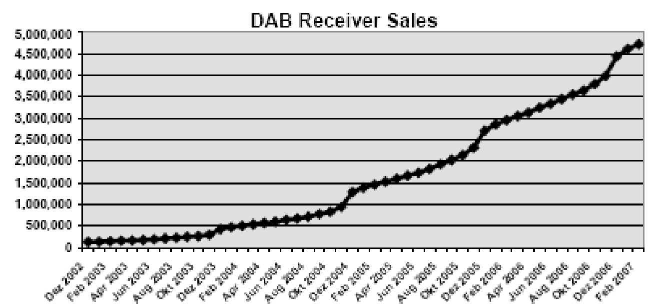


Figure.1: The DAB Receiver Sales since 2002 to 2007

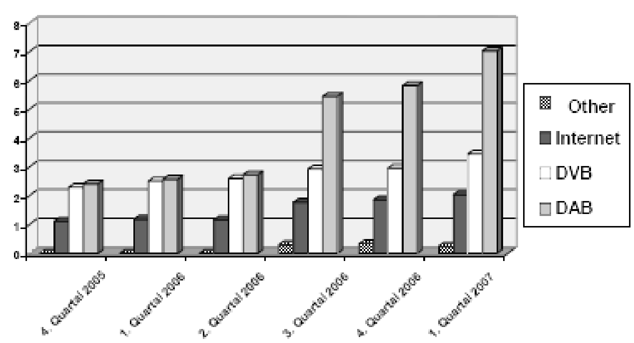


Figure.2: Growth of the various digital platforms

In 1986, the Eureka-147 digital radio project was launched with the objective to replace analog FM radio. The main goal of the project was to construct a system that delivered frequency efficient and CD-quality broadcasting to both mobile and stationary receivers.

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The DAB method was developed in Europe within the framework of Eureka project 147 and is currently being introduced in a large number of countries. [14]

The digital radio mondiale (one of the DAB standards) has voted to extend its broadcasting bands at up to 120MHZ. The digital radio mondiale (DRM) standard has been developed for operation in the AM band. This standard is able to broadcast over extremely long distances without the use of satellites. Thus, the digital technology improves broadcasting and reception qualities, allows the development of new production techniques and offers a greater variety of services than analog technology. And this benefits both broadcasters and audience.

II. The Role Of Anti-Alias Filter In The DAB Receivers

Fig.3 shows the block diagram of DAB receivers. After demodulation and prior to A/D conversion, additional filtering is required to avoid destructive aliasing from out-of-band signals. The low-pass filter that precedes the A/D converter is called anti-aliasing filter. This filter is located in the analog front-end circuits of DAB receivers.

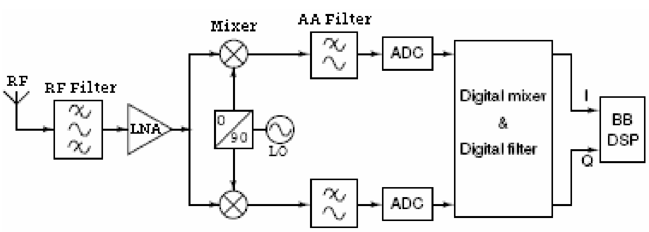


Figure.3: The block diagram of DAB receivers

Aliasing due to unwanted, spurious out-of-band signals is a problem in many applications that use A/D converters. These signals, if not filtered properly, can seriously impact the performance of a data-conversion system.

In processing analog signals using discrete-time systems, if the input is not band limited or if the nyquist frequency of the input is too high, prefiltering may be necessary. Also, even if the signal is naturally bandlimited, wideband additive noise may fill in the higher frequency range, and as a result of sampling, these noise components would be aliased into the low-frequency band. The block diagram of Fig.4 shows a continuous to discrete (C/D) conversion system that analog signal is converted to digital signal and anti-alias filter is used in a stage prior to A/D converters. [15]

For this architecture, the primary design challenges in the analog section are the A/D converter and its associated anti-alias filter.

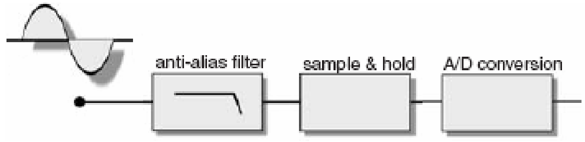


Figure.4: The position of anti alias filter in the C/D conversion system

The required sampling rate of the ADC is directly dependent on the combined out-of-band attenuation provided by the RF and anti-alias filters. When selecting a filter, the goal is to provide a cut off frequency that removes unwanted signals from the ADC input or at least attenuates them to the point that they will not adversely affect the circuit. The channel filter allows a signal of the desired band to pass, and attenuates the adjacent channel and the alternate channel interferer.

If an ideal frequency response was available, the anti aliasing filter would be fairly simple to design; unfortunately, ideal RF filters are not available and the analog circuit requirements increase accordingly. Ideally, the frequency response of the low pass filter would be:

$$H_{AAF}(j\omega) = \begin{cases} 1 & |\omega| < \omega_c < \dfrac{\pi}{T} \\ 0 & |\omega| > \omega_c \end{cases} \qquad (1)$$

If we wish to avoid aliasing, the input signal must be forced to be band limited to frequencies below one-half the desired sampling rate (nyquist sampling theorem). [15]

III. Gm-C Filter

In this project, we require sharp-cutoff anti aliasing filters. Such sharp-cutoff analog filters can be realized using active networks and integrated circuits. Analog integrated filters are mainly used before A/D converters in mixed analog digital systems as anti aliasing filters. Three main groups of integrated analog filters are: OPAMP-C, MOSFET-C and, Gm-C filters. In comparison to active-RC filters, Gm-C filters use OTAs instead of opamps to overcome effects of opamp nonidealities on active-RC filters. [10]

Also, OTAs have the advantages of easy tunability and generally simpler circuitry than most opamps. Gm-C filters are applicable in a wide range of frequencies from a few hertz in biomedical systems to several hundred mega hertz range in communication systems.

Furthermore, transconductance amplifiers have the following advantages: the transconductance varying with bias voltages, operating in a wide frequency range, high input impedance and high output impedance. Hence, the gm-c filter based on OTAs is better than the OPAMP-C and MOSFET-C filters.

Gm-C filters, also named OTA-C filters or transconductance-c filters are widely used in high frequency applications. The basic building block of a gm-c filter is an integrator involving a transconductor and a capacitor. A transconductor (gm) is a voltage controlled current source and it is tunable through varying DC bias current. [11], [12]

A gm-c integrator is shown in Fig. 5(a) that the output current (I_{out}) achieves by:

$$I_{out} = g_m.(\frac{1}{2}v_{id} - (-\frac{1}{2}v_{id})) = g_m.v_{id} \quad . \qquad (2)$$

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Fig. 5(b) shows the symbol of the symmetric transconductor.

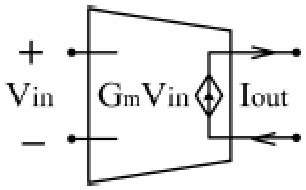


Figure.5 (a): A gm-c integrator

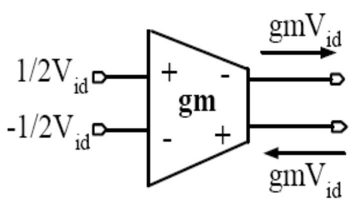


Figure.5 (b): The symbol of the symmetric transconductor.

IV. The Proposed Gm-C AAF Design

The construction of 4th order Gm-C filter is based on topology of passive RLC network, realization of resistors using transconductors and emulation of inductors using Gm-C gyrators.

Fig. 6 shows the basic AAF structure which is a 4th order passive LC ladder filter. Traditional RC-based filters with passive elements can not be directly applied in soc (system-on-chip) designs due to large area cost. Transfer function of the 4th order passive low-pass filter, as shown in Fig. 6, is given in (3).

$$\frac{v_{out}}{v_{in}} = \frac{R'}{RL_1L_2C_1C_2S^4 + (RR'C_1 + L_2)L_1C_2S^3 + PS^2 + QS + (R + R')} \quad (3)$$

$$P = L_1(RC_1 + R'C_2) + RL_2(C_1 + C_2) \quad , \quad (4)$$

$$Q = RR'(C_1 + C_2) + L_1 + L_2 \quad . \quad (5)$$

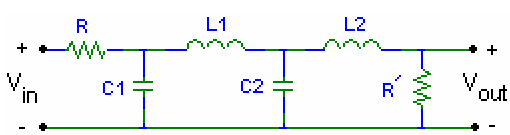


Figure.6: The 4th order butterworth passive LC ladder filter

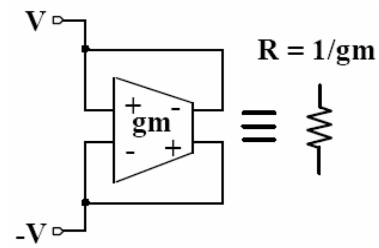
Passive inductors and resistors usually occupy large area on chip which is not acceptable in soc designs. The silicon area and power consumption are two most important factors in the integrated circuits.

Hence, the passive inductors are replaced with active inductors, whereas the resistors are replaced with active gm elements. One advantage of the gm-c filter is that passive components like the resistor and inductor can be realized with OTA and capacitor. The realization of resistor and inductor are shown in Fig.7 (a), (b). [1], [7]

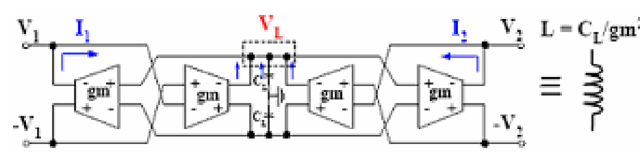
The inductance and resistance values, as shown in Fig.7, are given in (6), (7).

$$L = \frac{V}{I} = \frac{C_L}{g_m^{\ 2}} \quad , \quad (6)$$

$$R = \frac{V}{I} = \frac{V}{g_m . V} = \frac{1}{g_m} \quad . \quad (7)$$



(a) Equivalent circuit of the resistor



(b) Symmetrical floating gyrator which is equivalent to an inductor

Figure.7: The realization of resistor and inductor

The transconductance can be widely tuned by changing DC bias current. High linearity and wide bandwidth are achieved by using a transconductance (gm) cell, as shown in Fig. 8. The gm value can be approximated as

$$g_m = \sqrt{2.\mu.c_{ox}.\frac{w}{l}}.\sqrt{I_d} \quad , \quad (8)$$

$$= \mu.c_{ox}.\frac{w}{l}.v_{od} \quad . \quad (9)$$

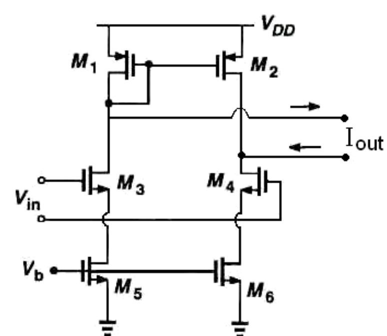


Figure.8: The proposed transconductor circuit (gm cell)

Equation (8) shows that it is possible to control the transconductance value through the tail current. On the other hand, equation (9) shows the proportionality between gm and the voltage overdrive. The upper limit of v_{od} is related to the limited voltage supply. In low-pass filter design, the cut off frequency of the filter is proportional to gm/c, where g_m is the transconductance of the OTA and C is the capacitance. [12]

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The relationship between the output current and the input differential voltage can be tuned by IM3 and IM4. With a suitable value of IM3, we can increase IM4 to increase the overall transconductance. Thus, we can increase the cut off frequency of anti-aliasing filter.

The transconductor is used as an operational transconductance amplifier (OTA) in the design of the 4th order butterworth low-pass filter.

Fig. 9 shows the fully differential gm-c biquad filter. Transfer function of gm-c block diagram of this filter, as shown in Fig. 9, is given in (10), that the variables of X and Y achieves by (11),(12).

$$\frac{v_{out}}{v_{in}} = \frac{g_{m1} \cdot g_{m4} \cdot g_{m6} \cdot g_{m7}}{c_1 c_2 c_L{}^2 S^4 + c_L{}^2 (g_{m9} c_1 - g_{m2} c_2) S^3 + XS^2 + YS - g_{m3} g_{m4} g_{m7} g_{m8}}, \quad (10)$$

$$X = c_L [c_1 (g_{m7} g_{m8} - g_{m5} g_{m6}) - g_{m2} g_{m9} c_L - g_{m3} g_{m4} c_2] \;, \quad (11)$$

$$Y = c_L [g_{m2} (g_{m5} g_{m6} - g_{m7} g_{m8}) - g_{m3} g_{m4} g_{m9}] \;. \quad (12)$$

V. SIMULATION RESULTS

A CMOS operational transconductance amplifier (OTA) for low-pass and wide tuning range filter application is proposed in this paper. A 4th order butterworth low-pass filter implemented with the OTAs is simulated by TSMC 0.18µm CMOS process.

With the use of the OTA as a building block in the gm-c filter architecture, the cut off frequency of the low-pass filter is achieved to 80MHZ. Fig.10 shows the frequency response of the gm-c anti aliasing filter with a 80MHZ cut-off frequency. The power consumption of the gm-c filter was 848.17µwatt through the supply voltage of 1.8V.

Also, this filter consumed 1.32 mwatt on a 1.8V power supply with 100MHZ cut off frequency, as shown in Fig.11. This result is better than the recent similar works with high power consumption.

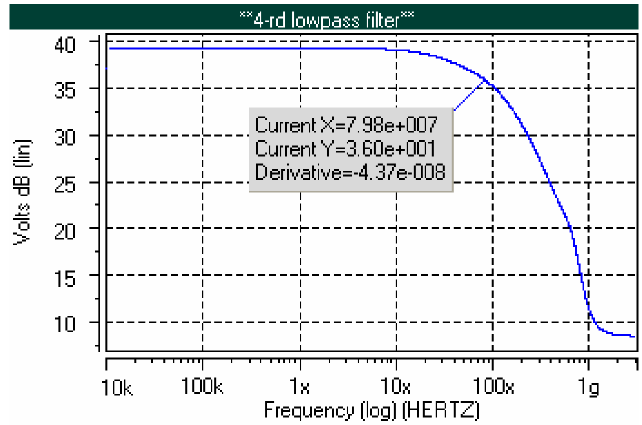


Figure.10: The frequency response of the gm-c filter with 80MHZ cut off frequency

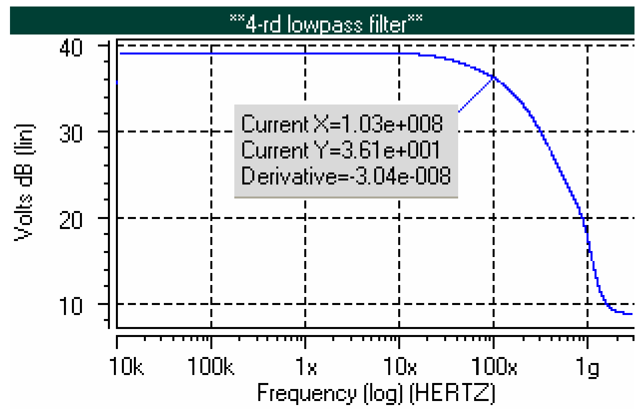


Figure.11: The frequency response of the gm-c filter with 100MHZ Cut off frequency

Table 1 summarizes the measured results of anti-alias filter in DAB receiver. In this paper, we achieved to minimize the power consumption in the digital radio receivers. These results are achieved by varying the aspect ratio of transistors and by varying the bias voltages. The transistor sizes and the value of capacitors and the bias voltages for this result are illustrated in table 2.

A comparison of the proposed design with several prior designs is summarized in table 3.

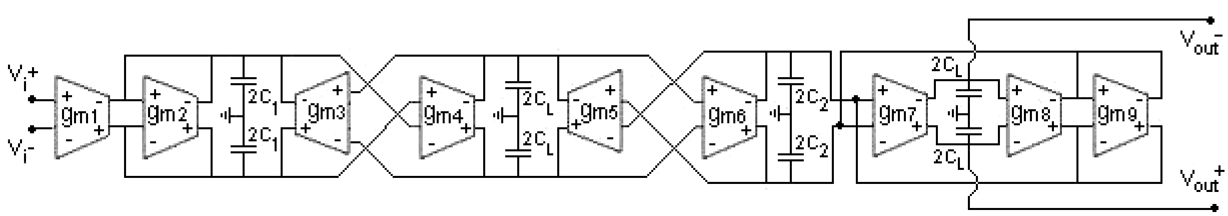


Figure.9: Active implementation of the passive anti aliasing filter

ISBN: 978-988-18210-7-2
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TABLE I. PERFORMANCE SUMMARY of MEASURED RESULTS

Technology		TSMC 0.18μm CMOS
Filter type		4^{th} -order Butterworth low-pass
Power Supply		1.8V
Result 1	Power consumption	848.17 μwatt
	Cut-off frequency	80MHz
Result 2	Power consumption	1.32 mwatt
	Cut-off frequency	100MHz

TABLE II. Gm-C Filter Parameters

Parameter	Value	
	Result 1	Result 2
$M_{1,2}$, $M_{7,8}$, $M_{13,14}$, $M_{19,20}$, $M_{25,26}$ $M_{31,32}$, $M_{37,38}$, $M_{43,44}$, $M_{49,50}$	20μm/0.3μm	20μm/0.3μm
$M_{3,4}$, $M_{9,10}$, $M_{15,16}$, $M_{21,22}$, $M_{27,28}$ $M_{33,34}$, $M_{39,40}$, $M_{45,46}$, $M_{51,52}$	10μm/0.5μm	10μm/0.5μm
$M_{5,6}$, $M_{11,12}$, $M_{17,18}$, $M_{23,24}$, $M_{29,30}$ $M_{35,36}$, $M_{41,42}$, $M_{47,48}$, $M_{53,54}$	15μm/0.75μm	15μm/0.75μm
$V_{b_{1,2,3,4,5,6,7,8,9}}$	0.55V	0.58V
C_1, C_2, C_L	0.01PF	0.01PF

TABLE III. COMPARISON WITH PRIOR DESIGNS

	Filter type	CMOS PROCESS	Cut-off freq.	Power Consumption	POWER SUPPLY
[2]	5^{th} order elliptic	$0.18\mu m$	250Hz-1MHz	0.8mW	1.8V
[5]	5^{th} order Butterworth	$0.35\mu m$	330MHz	43mW	± 1.65 v
[8]	3^{th} order Butterworth	$0.18\mu m$	900KHz -2MHz	3.2mW	1.8V
[3]	3^{th} order Butterworth	$0.18\mu m$	500KHz -20MHz	11.1mW	1.2V
This work	4^{th} order Butterworth	$0.18\mu m$	80-100 MHz	848.17 μwatt 1.32 mwatt	1.8V

VI. CONCLUSIONS

Baseband circuits in a direct conversion receiver can be implemented with a continuous-time anti aliasing filter and the A/D converter.

The low-pass filter that precedes the A/D converter is called anti-aliasing filter. This filter is located in the analog front-end circuits of DAB receivers. In 1987, European project Eureka 147 was formed, in order to develop a new digital radio broadcasting system.

This work presents a CMOS implementation of a low-power 4^{th} order Butterworth low-pass gm-c filter for a very wide frequency tuning range, which can operate as the channel selection filter for the audio speech, bio medical and wireless application.

The 4^{th} order butterworth low-pass filter design is initialized by a standard 4^{th} order butterworth low-pass LC-ladder prototype.

Gm-C filters are built with transconductance elements and capacitors, to take advantage of these structures for making integrators at high frequencies. The anti-aliasing gm-c filter is simulated in the TSMC 0.18μm CMOS technology.

In this work, we were able to minimize the power consumption and the number of transistors in such circuits. This circuit consists of 54 MOSFET transistors and consumes 848.17μwatt on a supply voltage of 1.8V with 80MHZ cut-off frequency.

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