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A GM-C LOW-PASS FILTER WITH AUTOMATIC TUNING IN 100KHz TO 3MHz RANGE FOR ZERO-IF RECEIVERS

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ABSTRACT

A third order low-pass Butterworth Gm-c filter is used to maximize the tuning range is described. This filter is used as a channel-Selection/anti-aliasing filter in the base-band of a Zero-IF receiver architecture. The cutoff frequency of this filter is from 92KHz to 3.5MHz.In the worst-case the power consumption reaches 2.16mw.

The technology used in this structure is a 0.35 standard CMOS. Low working voltage and low power consumption and economical aspects are reasons to choose CMOS technology.

The linear transconductor is on the basis of Drain voltage changes of the biased input Transistor in the Triode region.

Total Distortion of filter in 92KHz cutoff frequency, and with input frequency of 100KHz reaches 1% and this filter works with 3.3 input voltage.

KEYWORDS: Base-Band Filter, Gm-C Filter, Index Terms Butterworth Filter, Wide Tuning Range, Zero-IF Receiver

INTRODUCTION

For simplicity of the design Multi-standard transconductors are used, to have such an standard there should be an attempt to concentrate on the base-band analog filter finite important parameters.

The notable point of this work is to design a low-pass band filter with continues tuning, wide range that works for a Zero-IF Receiver between mixer and A/D converter. The wide and continues tuning range provides band width for different standard utilities.[1]

There are several important communication standards such as GSM, Bluetooth, CDMA, W-CDMA and widest cutoff frequency range is given by GSM,W-CDMA and it is between 115KHz and 1.2MHz and the tuning cutoff frequency ratio, $\left(\frac{F_{\max}}{F_{\min}}\right)$ is around 20.

FILTER ARCHITECTURE

In this design (see figure1) third order Butterworth filter transconductor function in ladder network is used, and this architecture is implemented using transconductance. (see figure 1) If no capacitor is used the simple structure's tuning ratio will be around 30. A single filter (see fig1) can hardly provide the tuning range, due to linearity, noise and power consumption (see figure 2),

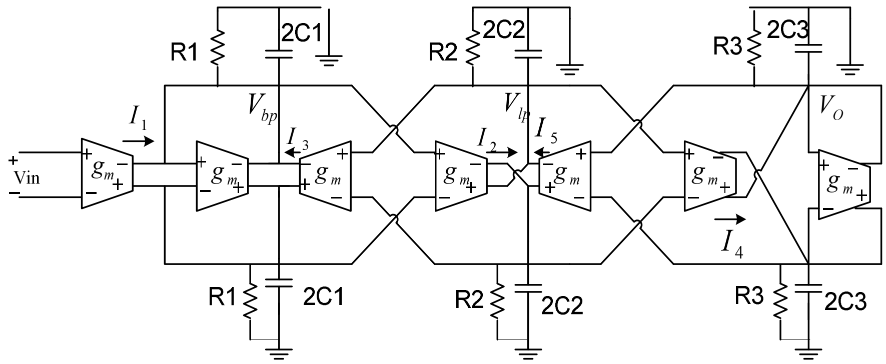

Figure 1: Third Order Low-Pass Butterworth Filter

so we have to use multi-Gm architecture to maximize the ratio , $\left(\frac{F_{\max}}{F_{\min}}\right)$.(see figure 3). [2]

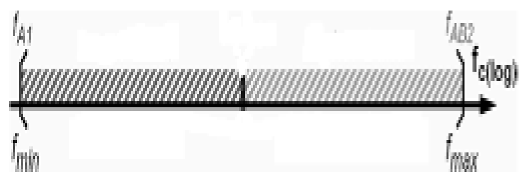

Figure 2: Cutoff Frequency Domain Set

F_{min}= 100KHz, F_{max}=3MHz

In the presented design two equal capacitors are paralleled with blocks consisting of transconductor banks. So the effective transconductors used in the design are the same, and equal to gm [2]. The suggested design consists of two paralleled transconductor banks (named A, B).

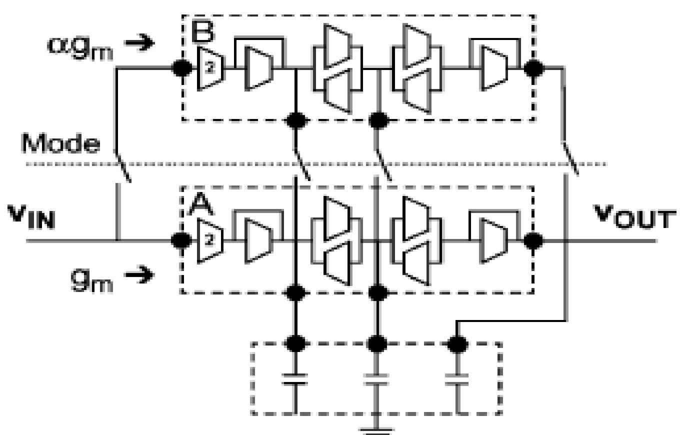

Figure 3: The Multi Gm Architecture

One of the blocks is always switched on (Block B), and the other is switched off. The value X represents the maximum reachable ratio $\left(\frac{G_{m\max}}{G_{m\min}}\right)$ for each transconductor. So we can define the effective transconductor as

$G_m = \frac{G_{m\max}}{\sqrt{X}} = G_{m\min}.\sqrt{X}$. Block A has a transconductance of G_m and block B has an effective transconductance of αG_m .

When both blocks are connected to each other by capacitors, the effective transconductance will be $(1+\alpha)G_m$. According to fig4, the narrowest tuning bandwidth is defined for the state, that only switch a is on.

Cut off frequency is from $F_{A1} = \frac{G_m}{2\pi C\sqrt{X}}$ to $F_{A2} = \frac{G_m\sqrt{X}}{2\pi C}$.

The widest tuning bandwidth occurs when both A and B are connected by a capacitor and cutoff frequency range is between $F_{AB1} = \frac{(1+\alpha)G_m}{2\pi C\sqrt{X}}$ and $F_{AB2} = (1+\alpha)G_m\sqrt{X}$.

To reach the maximum range of transconductor tuning , the highest cutoff frequency in lowest band should be equal with the lowest cutoff frequency in the highest band.($F_{AB1} = F_{AB2}$)

To achieve this α has to be α=X-1, then the total cutoff frequency range of this structure is from $\frac{G_m}{2\pi C\sqrt{X}}$ to $\frac{G_m X^{\frac{3}{2}}}{2\pi C}$. The ratio $\frac{F_{\max}}{F_{\min}}$ in this structure has an effective tuning ratio that has the same value with transconductor tuning ability to a power o two $\left(\frac{F_{\max}}{F_{\min}} = X^2\right)$, Because the transconductor is entirely multiplied by X. In this design the ratio $\frac{F_{\max}}{F_{\min}}$ exceeds 30 and it leads the transconductor tuning ratio to be around 6.($\sqrt{30} \approx 6$)

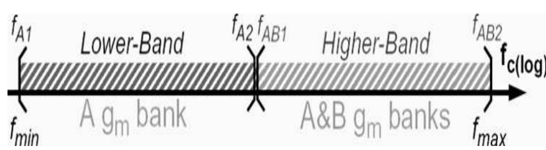

Figure 4: Cutoff Frequency Domain Set

PROPOSED METHOD

In Gm-C filter design, designing of a low power consumption, wide Tuning range, economical aspects and Low working voltage is considered.In this case, Gm-C filter is proposed that uses CMOS technology.

Transconductor Design

Principles

In this Study, third order low-pass Butterworth Gm-c filter was employed.The requirements for linearity/distortion depend on standard and system.

The need for a transconductor with wide tuning range and stringent linearity leads to use of MOS Transistors in Triode (linear) region, Since in this situation MOS Transistor transconductance can be varied by changing the V_{DS} value of transistor.

The drain current first order equation of a linear Transistor is described by the equation below;

$$I_D = \mu_n cox\left(\frac{W}{L}\right)V_{DS}\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)$$

And from the V-I characteristic we can write ; $g_m = \frac{\delta I_D}{\delta V_{GS}} = \mu cox\left(\frac{W}{L}\right)V_{DS}$

According to previous equations, it can be understood that g_m in relation with V_{DS} and it doesn't depend on any other voltages such as V_{GS}.

The linear correspondence between output current and input voltage is valid until Transistor operates in linear (Triode) region ($V_{GS} - V_T > V_{DS}$)

According to figure (5), both Transistors M_{11} and M_{22} are operating in linear region and Transistors M_1 and M_2 are to fix Drain voltage.

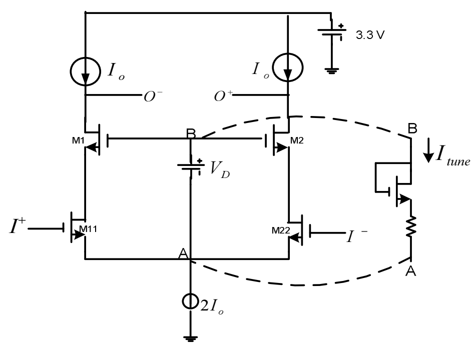

Figure 5A: Unit Transconductor **Figure 5B: V_{DS} Control**

The linear characteristics of this design are highly dependant on M_{11} and M_{22} Transistors' V_{DS}, because M_{11} and M_{22} large signal transconductance is directly in relation with their V_{DS}.

As a result the cascode Transistor will have the highest reachable transconductance ,so that it can fix M_{11} and M_{22} Drain voltages despite large current variations. CMFB (common mode feedback) is used to increase the low working voltage. CMFB circuit is shown in figure (6).

The CMFB bias current is adjusted to half the bias current of V-I converter to reduce power consumption. M_{33} and M_{44} Transistors are operating in linear region and maximizing V_{DS} will maximize their intrinsic transconductance and consequently making CMFB performance better.

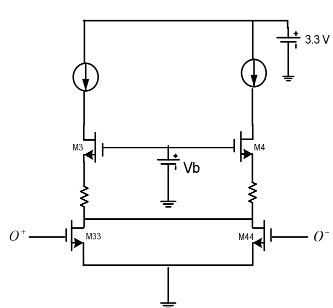

Figure 6: CMFB Circuit

Tuning Circuit

According to fig (5), transconductance tune will be done by the means of controlled voltage source, that is between M_1 and M_2 Transistors.(fig 5A, node B) and M_{11} and M_{22} Transistors.(node A)

A diode-connected Transistor that is in series with the resistor R_{tune} between two nodes, is inserted to control the linearity of M_{11} and M_{22} Transistors' V_{DS} through the current V_{GS-} V_T (I_{tune}). But these changes are small and tuning range is limited by the MOS Transistors' operation region limits. V_{GS-} V_T value of M_{11} and M_{22} Transistors will define the upper limit of V_{DS} to keep the Transistor in linear region and the lower limit of V_{DS} is so that, bias current of source ($2.I_o$) will remain in saturation region. Figure (7) shows the designed circuit. By increasing the V_{DS} tuning range, transconductor tuning range will be maximized.

The maximum desirable ratio, $\frac{G_{m\max}}{G_{m\min}}$ is around 6, and by proposed design we will reach the ratio, $\frac{F_{\max}}{F_{\min}} \cong 40$

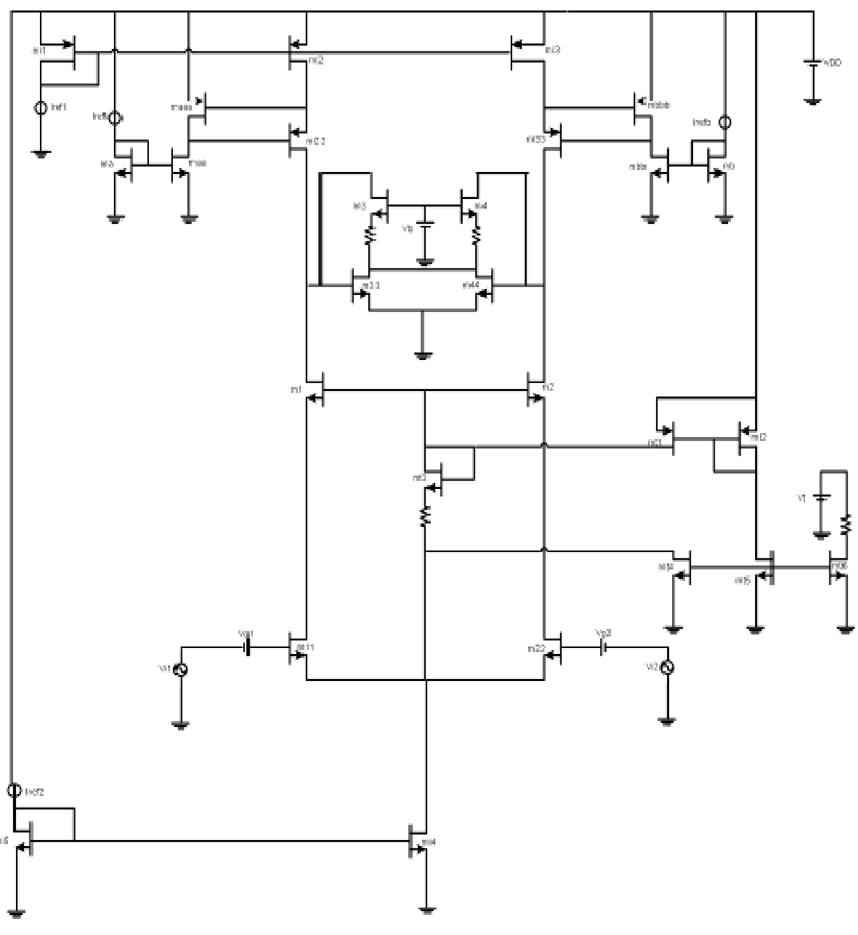

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Figure 7: Proposed Transconductor Design

SIMULATION

The third order low-pass Butterworth Gm-c filter with employed Gm-c, was simulated by Hspice software in 0.35 μm technology. The results will discuss latter. Figure 8A,8B shows filter frequency response with Minimum and Maximum cutoff frequency of the lowest band.

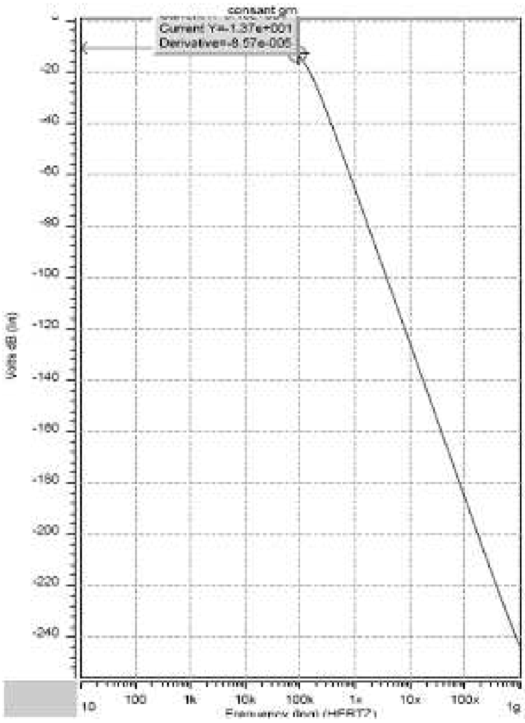

Figure 8A: Maximum Cutoff Frequency of the Lowest Band

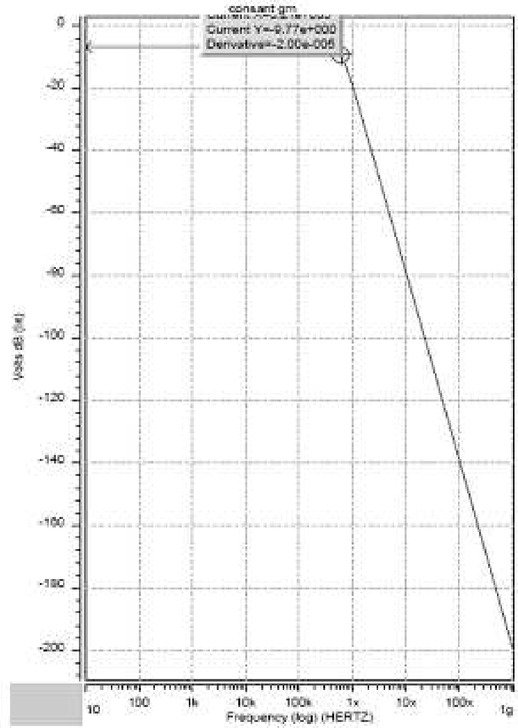

Figure 8B: Minimum Cutoff Frequency of the Lowest Band

Figures 9A, 9B shows filter frequency response with Minimum and Maximum cutoff frequency of the highest band.

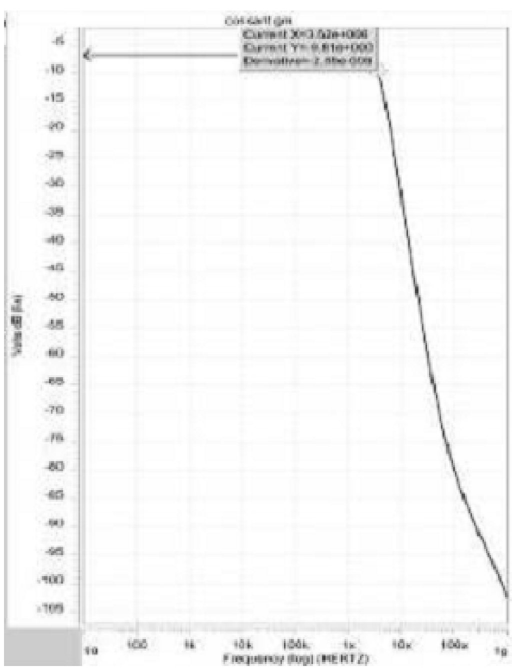

Figure 9A: Maximum Cutoff Frequency of the Highest Band

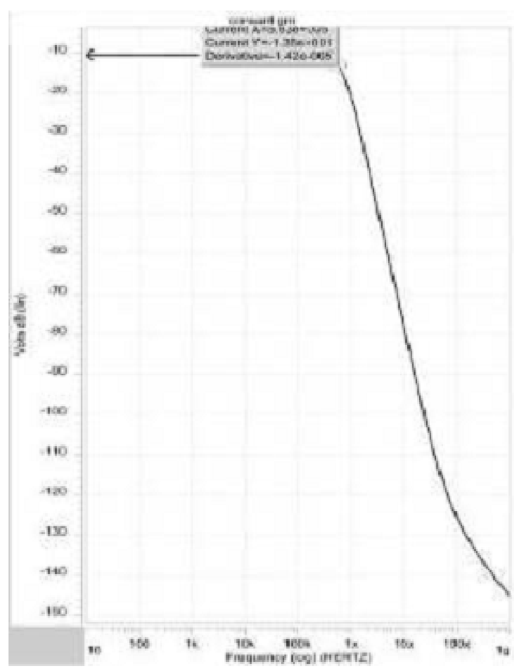

Figure 9B: Minimum Cutoff Frequency of the Highest Band

Table 1: Comparison with Previous Works

Refernce	Used Technology	Filter Order	Cutoff Frequency	Power Consumption	Tuning Range	Distortion	Voltage Source
1	Gm-C CMOS (0.5μm)	Fifth order Elliptic	2MHz	115 mW	-	-	2.5V
2	Gm-C BiCMOS (0.25μm)	Third order Butterworth	50KHz 2.2MHz	7.3mW	40	-	2.5V
3	Gm-C CMOS (0.8μm)	Fifth order Elliptic Elliptic	4MHz	10 mW	-	57.6 dB	3V
This work	Gm-C CMOS (0.35 μm)	Third order Butterworth	92KHz 3.5MHz	2.16mW	40	56.7dB	3.3V

CONCLUSIONS

The circuit tuning range is about 1:40 and cutoff frequency range is from 92KHz to 3.5MHz and Total Distortion of filters 1% for cutoff frequency of 92KHz, and input frequency of 100KHz. Variation limits of block A(lowest band) Transconductance are 60μs and 10μs ($10\mu s<g_m<60\mu s$) and limits of Block B(highest band) are 45μs and 280μs ($45\mu s<g_m<280\mu s$) and used capacitor size is C=1pf.

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