70 MHz CMOS Gm-C Bandpass Filter

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ABSTRACT

A CMOS Gm-C bandpass filter with a center frequency of 70 MHz and a bandwidth of 3 MHz is presented. The operational transconductance amplifier (OTA) presented in this paper along with the capacitors (Gm-C filter) is used in designing the biquad structure. The filter is realized in 0.18 ì CMOS technology using Virtuoso analog environment in Cadence tool. The simulation result shows the AC response of the filter with a center frequency of 69.98 MHz, bandwidth of 3.32 MHz and a gain of 18.46 dB.

Index Terms—Bandpass filter, biquad, operational transconductance amplifier (OTA), Super-heterodyne receivers.

1. INTRODUCTION

HIGH performance cellular phones with low cost and small size have increasing demand in today's market. The primary criterion in various cellular phone design approaches include lowering the complexity, cost, power, and number of external components. The super-heterodyne structure achieves good selectivity and avoids the problem of DC offset in homodyne (direct-down) receivers and this is mainly utilized in the wireless receivers for mobile phones. IF bandpass filters are then needed for the channel selection and filtering. In super-heterodyne receivers shown in figure 1, proper filtering is mandatory and is done by external surface acoustic wave (SAW) filters [1].

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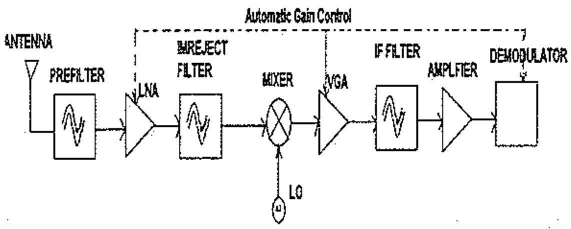

Figure 1. Super- heterodyne receiver

High Q, stable center frequencies and no extra power for operation are some of the advantages of using external filters (especially SAW filters). But in order to drive the 50Ω input impedance of these off-chip filters, much power (hundreds of mW) has to be supplied for the drivers. More noise is coupled into the external connections too. Also, external filters are large and expensive, but they are unavoidable in super-heterodyne architectures. Since these filters are not implemented monolithically, they are the major impediment to increasing the level of integration of wireless radio. This is the motivation behind the design of monolithic receivers with on-chip filters.

There are various designs of on-chip bandpass filters including simple RC filters, switched-capacitor (SC) filters, spiral inductor-capacitor tanks and Gm-C filters. The simple RC filters suffer from variation of resistors and capacitors. Each resistor has to be tuned after fabrication. SC filters solve the mismatch problem of the RC filters accurately in CMOS processes. However, SC filters are not suitable for frequencies above 10 MHz due to the strict requirement of the unity-gain frequency of operational amplifier (opamp) for fast settling. Spiral inductors are only suitable for high frequencies of GHz range. For operation in the IF band, which is from 10

MHz to 100 MHz, however, the Q of these inductors are too low (smaller than 1) to be compensated. A lot of chip area is required for the large inductors and the large capacitors .The resistance of the inductors dominates the reactance of the inductance. [6].

Filtering can be done by making use of active filters. The Gm-C circuits represent a popular technique of integrated realisation of high frequency continuous time filters [1]. The Gm-C filter offers many advantages in terms of low-power and high frequency capability.Gm-C filters can operate in a wide range of frequencies from several hundred of KHz to more than 100 MHz. Unlike the spiral inductors, the Q of Gm-C filters can be adjusted by controlling the output impedance even at lower frequencies. Therefore, for the IF band, Gm-C filter is a good choice for on-chip filtering. The main objective of this paper is to design a bandpass filter for super-heterodyne receivers. The filter design is presented in section II.Section III gives the implementation and simulation results. Finally, conclusion is drawn in section IV.

2. Filter Design

A. Operational Transconductance Amplifier (OTA)

The operational transconductance amplifier (OTA) is basically an op-amp without an output buffer. An Operational transconductace amplifier without buffer can only drive capacitive loads. An OTA can be defined as an amplifier where all nodes are low impedance except the input and output nodes. The transconductance of the OTA is given by

$$g_m = \frac{i_{out}}{v^+ - v^-} \qquad (1)$$

where i_{out} is the output current of the OTA and v^+ and v^- is the differential input voltage to the OTA. The voltage gain of the OTA is given by

$$A_v = \frac{v_{out}}{v^+ - v^-} \qquad (2)$$

where v_{out} is the output voltage of the OTA. The OTA used in designing the bandpass filter [2] is shown in

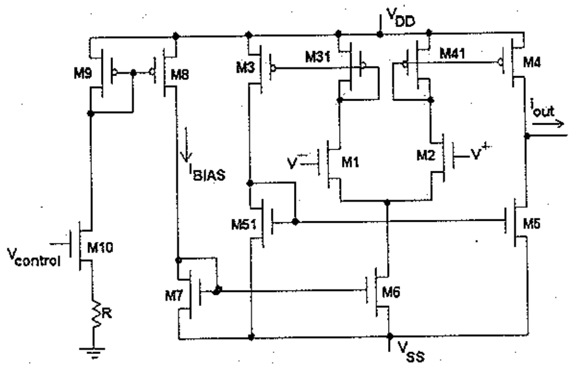

Figure 2 : Schematic of OTA

TABLE I
CIRCUIT PARAMETERS FOR OTA

Device	Value
PMOS(W/L)	22μ/0.18μ
NMOS(W/L)	02μ/0.18μ
R	100KΩ
I_{bias}	10μ A

figure 2.The circuit parameters for OTA are given in table I.

The symbol for OTA is shown in figure 3. A useful feature of OTA is that its transconductance can be adjusted by the bias current. Filters made using the OTA can be tuned by changing the bias current labeled I_{bias}.Two practical concerns when designing an OTA for filter applications are the input signal amplitude and the parasitic input/output capacitances. Large signals cause the OTA gain to become non-linear. The external capacitance should be large compared to the input or output parasitic of the OTA.This limits the maximum frequency of a filter built with an OTA and causes amplitude or phase errors .These errors can usually be tuned out with proper selection of I_{bias}.

A. Gm-C biquad (2nd order bandpass filter)

The biquad implement's the bandpass function [3-6]. The biquad implemented for filter design is shown in figure 4.

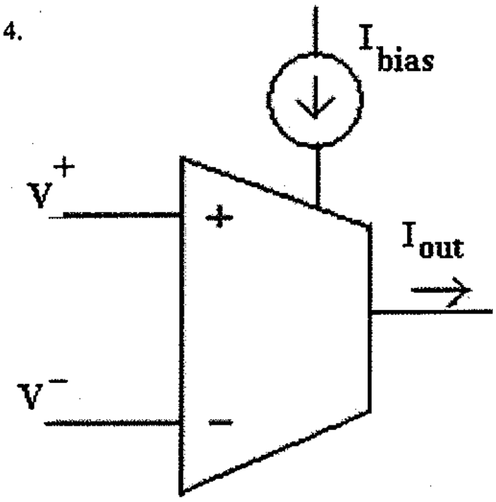

Figure 3 : Symbol of OTA

The input condition for the biquad filter is

$V_2 = V_{in}$

$V_1 = \text{ground}$

$V_3 = \text{ground}$ (3)

where V_1, V_2, V_3 are the inputs to the biquad as shown in figure 4.

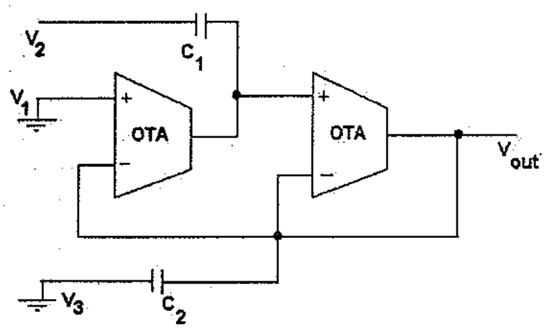

Figure 4 : Biquad filter implementations using OTAs.

Both the OTAs are implemented in the same manner and the transconductance of each stage is same. The circuit parameters of the biquad (second order filter) are given in table II.

The transfer function of the second order bandpass filter is given by

TABLE II
CIRCUIT PARAMETERS FOR BIQUAD

Device	Value
C_1	0.225pF
C_2	0.925pF

$$H(s) = \frac{sC_1 g_m}{s^2 C_1 C_2 + sC_1 C_2 + g_m^2} \quad (6)$$

The filter design specification is given in table III.

3. Results

The proposed bandpass filter is designed and simulated using Virtuoso Analog Environment in Cadence tool and the following results are obtained.

TABLE III
FILTER DESIGN SPECIFICATIONS

Application	Mobile applications.
Filter type	Active Gm -C
Center frequency	70 MHz
Bandwidth	3 MHz
Order of the filter	2
Technology	0.18µ CMOS
Power supply	1.8 V

A. Schematic and Results of OTA

The proposed OTA is implemented and simulated. The schematic diagram and the instance (symbol) for OTA are shown in figure 5 and figure 6 respectively. The bias current is set as 10 µA. The control voltage is set as 1V.The resistance value is set to 100 KΩ. The non-inverting input voltage is set as 10 mV and the inverting input voltage is set as 5 mV.

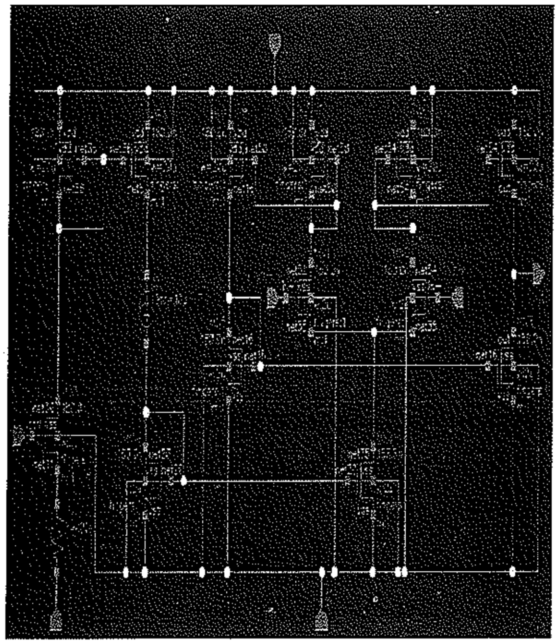

Figure 5 : Schematic of OTA

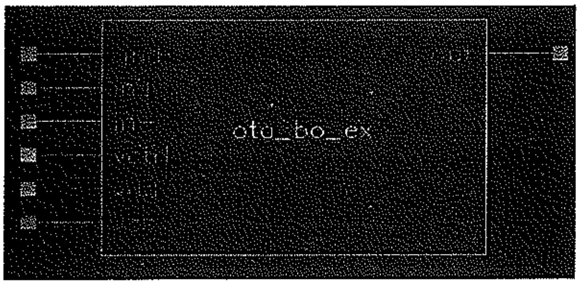

Figure 6 : Symbol of OTA

Hence, the differential input voltage is

$$in_{differential} = (10\text{ mV} - 5\text{ mV})$$

$$= 5\text{ mV}$$

The transient analysis for the OTA is done and the output current (i_{out}), and the input differential voltage (in^+ and in^-) are plotted. The transient response is shown in figure 7 with output current and input differential voltage. The transconductance value of the OTA is calculated using equation (1).

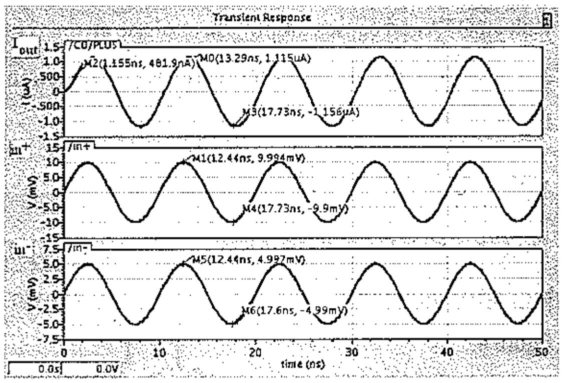

Figure 7 : Transient response of OTA

Calculation of transconductance

$$g_m = \frac{2.675\mu A}{10mV}$$

$$= 267.5\ \mu S$$

B. Schematic and Results of bandpass filter

The OTA implemented is combined to form a biquad as shown in figure 8. The AC response of the biquad is shown in figure 9. The 3dB bandwidth obtained is 3.32 MHz and the maximum voltage gain is 18.46 dB. This shows an improvement in gain and bandwidth as compared to existing structures [7-9].The simulation results are given in table IV.

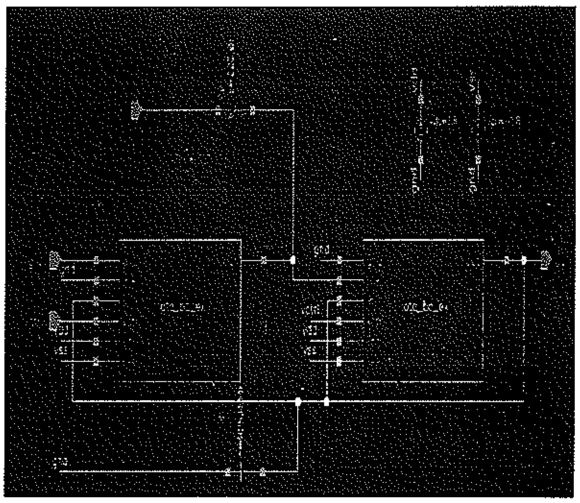

Figure 8 : Schematic of biquad

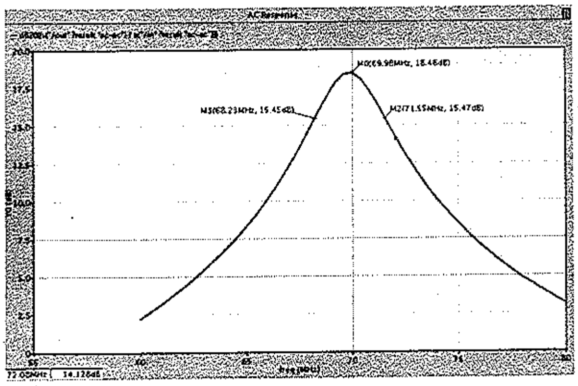

Figure 9 : AC response of the filter

TABLE IV
SIMULATION RESULTS

Center frequency	69.98 MHz
Bandwidth	3.32 MHz
Gain	18.46 dB
Transconductance of single OTA	267.5 μS
Power consumption	0.578 mW

4. Conclusion

The bandpass filter is designed and implemented in Virtuoso analog environment in Cadence tool for a center frequency of 70 MHz and bandwidth 3 MHz The filter is designed in 0.18 μ CMOS process. The gain can be increased further by cascading the OTAs to design higher order filters. Also common mode feedback block need to be introduced in order to fix the output drain voltages.

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