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TELESCOPIC OTA BASED KHN FILTER

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Abstract—**Analog filters are being employed in various signal processing applications especially second order filters in the design of higher order filter structures. KHN filter is an example of second order "biquad" analog filter which is used as a reference filter in designing of higher order filters. The vicinity of KHN filter makes it very suitable in designing various filtering circuits using several active elements as it provides very optimal results. In our proposed design KHN filter is implemented using telescopic OTAs and capacitors. The active element, telescopic OTA, is so chosen as to get large bandwidth, high speed and low power consumption since these parameters are major considerations in design of any filter circuit. The simulation results are verified using TANNER TOOL.**

Index Terms— **Biquad, OTA, Telescopic OTA, KHN Filter.**

I. Introduction

A filter in general term refers to a system which passes the desired things to a user and rejects the undesired things. In the similar fashion, a filter in an electrical network allows the passage of a desired range of frequencies and rejects or suppresses undesired frequencies. Passive filters and active filters are the two types that categorize the filters. Passive filters are not employed in most of the signal processing circuits as they cannot provide gain to the signal and their input and output impedence is very far from desired values. Hence active filters are being employed in most of the signal processing and filtering circuits.

Earlier methods of implementing an active filter employ the use of operational amplifier (op-amps). However operation amplifiers have small bandwidth and hence their cut-off frequency is low (kHz) and are not suitable for very high frequency (MHz) applications [1]. Hence for overcoming this drawback of op-amps various transconductance amplifiers came into existence among which operational transconductance amplifiers (OTA) are being widely used today due to their bias current controlled transconductance. An OTA is basically an op-amp without output buffer in which the transconductance g_m is controlled by a dc bias current which is controlled by through bias voltage across an OTA.

"Biquads", generally called as second order transfer function, is basically used as a base component in designing higher order continuous time filter because of its simplicity in predicting the characteristics of the desired output.

Kerwin, Huelsman and Newcomb presented the KHN filter which is basically a biquadratic filter with "two integrators in the feedback loop" structure [2]. In this report we have proposed a telescopic OTA based KHN filter. Simulation of the filter is done through TANNER TOOL for studying the behaviour of different parameters such as frequency response, phase response and power consumption.

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II. TELESCOPIC OPERATIONAL TRANSCONDUCTANCE AMPLIFIER

The Operational Transconductance amplifiers are primary and noteworthy building blocks in designing of numerous of different analog circuits and systems which were previously implemented by using OP-AMP. The operational trans-conductance amplifier (OTA) is basically a voltage controlled current source (VCCS) whose output current is produced by differential input voltage. The OTA is analogous to a standard Operational Amplifier in a manner that it offers high impedance at differential input stage and can also be used with negative feedback [3]. The operational transconductance amplifier can also be thought of an op-amp without an output buffer.

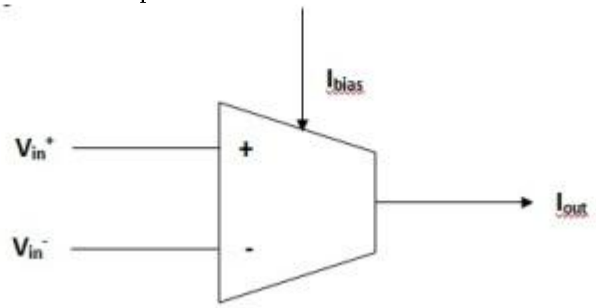

Fig. 1 Symbol of an OTA

The output current of an OTA is given by

$$I_O = g_m (V_+ - V_-)$$

And the transconductance is given as

$$g_m = \frac{Ic}{2Vt}$$

Telescopic architecture is the simplest version of the single stage OTA which is capable of providing high gain, high speed and very low power consumptions in comparison to other OTA topologies. Generally a telescopic operational amplifier has reduced dynamic range due to smaller swing. This is somewhat due to the lower noise factor of the Telescopic OTA which makes it very much suitable for low power and low noise operation. The architecture of a telescopic OTA is shown fig. 2. It can be seen in the architecture that transistors are placed one on the top of the other and create a sort of Telescopic composition which led to the circuit name as telescopic OTA.

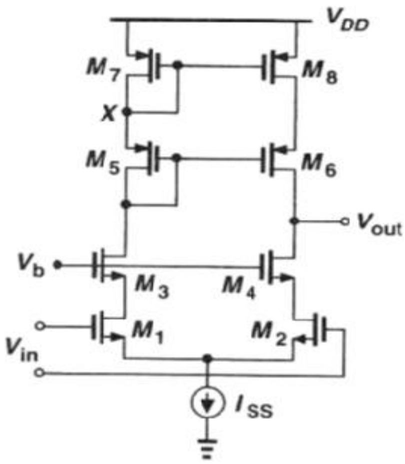

Fig. 2 Circuit diagram of a typical Telescopic OTA

The signal current is injected into the common gate stages through input differential pair. Then, the cascode current mirror helps the circuit in achieving the differential to single ended conversion. The telescopic cascode achieves a similar gain like the one of the two stages architecture, without having two poles close to each other. All the nodes have pretty small signal resistance excluding the output node.

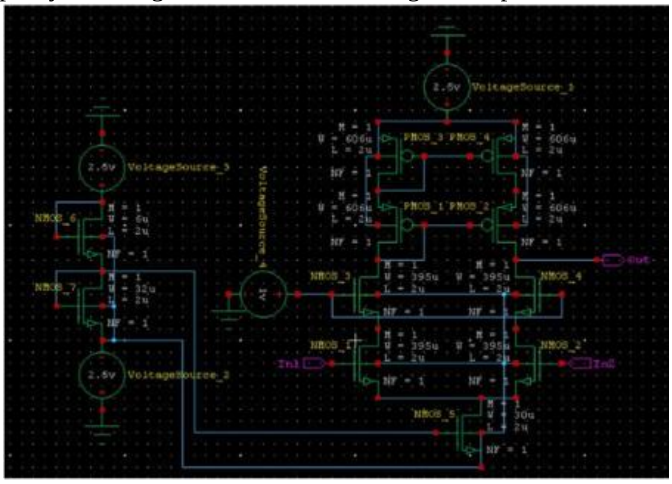

Fig. 3 Circuit implementation of Telescopic OTA

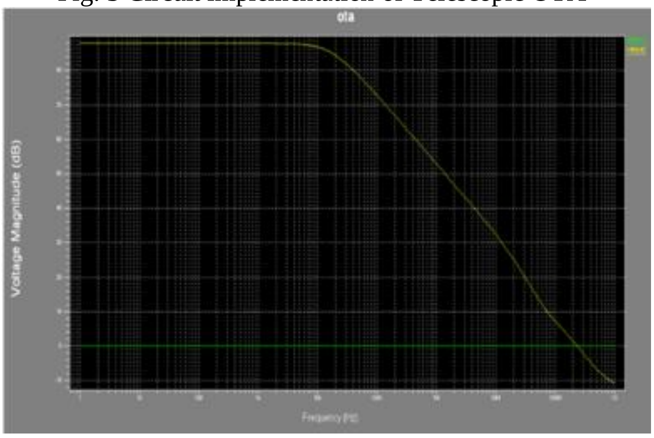

Fig. 4 Frequency response of the Telescopic OTA with bias circuit at its tail

III. KERWIN-HUELSMAN-NEWCOMB (KHN) FILTER

The Kerwin–Huelsman–Newcomb (KHN) is most commonly used biquad filter which belongs to the “two integrators in the feedback loop” type of filter structures. In general two voltage mode op-amp integrators and one adder construct the basic KHN circuit [4]. KHN is a second order biquad filter whose center frequency and Q factor can be varied independently and is one of the applications of the state variable method [6]. A significant characteristic of this filter structure is that all three basic filter transfer functions, i.e., low-pass (LP), band-pass (BP), and high-pass (HP) are generated simultaneously. The KHN filter has extreme flexibility, low sensitivities and provides good performance [5].

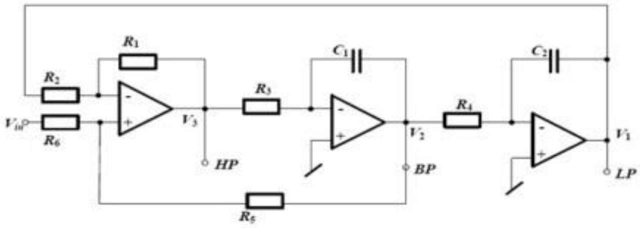

Fig. 5 Typical structure of KHN filter

A voltage-mode 2nd-order KHN filter in shown in fig. 5 which is the most favored building block in designing the cascade filter. The above circuit can be understood as a single-input three-output device which generates three basic 2nd-order filter transfer functions (low-pass, band-pass, and high-pass) simultaneously.

IV. PROPOSED MODEL

In this section design of KHN filter is proposed using Telescopic OTA. Further frequency response of all three basic filter transfer functions are verified using TANNER TOOL.

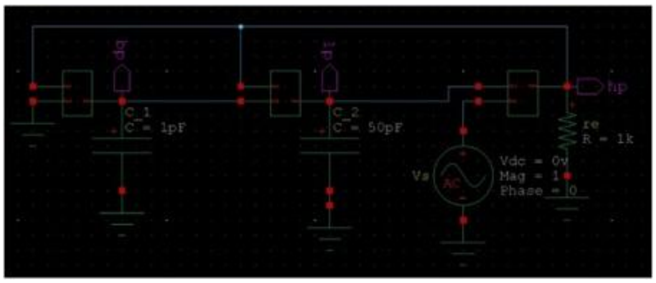

Fig. 6 Simulation model of OTA based KHN filter

MOS	W/L (μm/μm)
M1	395/2
M2	395/2
M3	395/2
M4	395/2
M5	303/1
M6	303/1
M7	303/1
M8	303/1
M9	30/2
M10	6/2
M11	32/2

Table 1 Calculated aspect ratios for the Telescopic OTA

The above figure represents the proposed model of our work and the table represents the calculated aspect ratios for the proposed model. The signal flow graph for the proposed model is given as

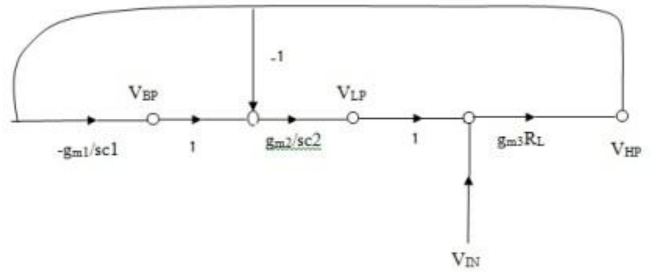

Fig. 7 Signal flow graph of the proposed model

The transfer function of the above proposed filter is being derived as follows

Transfer function of High Pass filter

$$\frac{V_{HP}}{V_{in}} = -\frac{S^2 g_{m3} R_L}{\Delta}$$

Transfer function of Band Pass filter

$$\frac{V_{BP}}{V_{in}} = -S\frac{\frac{g_{m1} g_{m3} R_L}{C_1}}{\Delta}$$

Transfer function of Low Pass filter

$$\frac{V_{LP}}{V_{in}} = \frac{\frac{R_L g_{m2} g_{m3}(g_{m1} + sc_1)}{c_1 c_2}}{\Delta}$$

$$\Delta = S^2 + S\frac{g_{m2} g_{m3} R_L}{C_2} + \frac{g_{m1} g_{m2} g_{m3} R_L}{C_1 C_2}$$

$$w_0 = \sqrt{\frac{g_{m1} g_{m2} g_{m3} R_L}{C_1 C_2}}$$

$$Q = \sqrt{\frac{C_2 g_{m2}}{C_1 g_{m2} g_{m3} R_L}}$$

where w_0 = cut-off frequency;
Q = quality factor

V. SIMULATION RESULTS

The proposed model is simulated using TANNER TOOL 13.0.

The OTA was realized by the CMOS implementation in fig. 2 using 0.18µm CMOS technology. The aspect ratios of the MOS transistor are given in Table 1. The supply voltages were taken as V_{DD}= 2.5 V, C_1=1 pF, C_2=50 pF, $g_{m1}=g_{m2}=g_{m3}$=1.17 mS and R_L=1 kΩ realizes a frequency of 28.33 MHz. The filter responses and simulated magnitude responses of low pass, high pass and band pass taken from different output terminals are shown in Fig. 8 respectively.

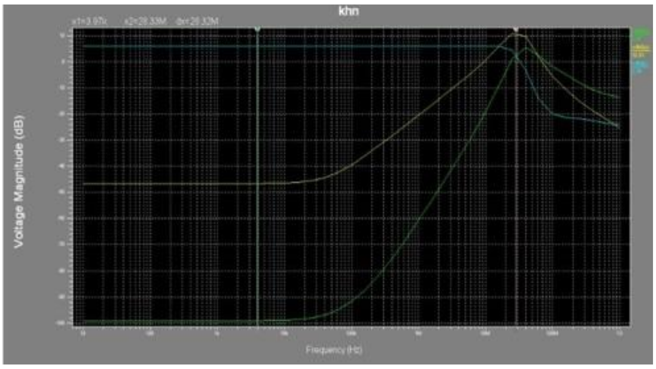

Fig. 8 Filter response

VI. CONCLUSION

The proposed KHN circuit uses three Telescopic OTAs, two capacitors and one resistor. The main reason for employing Telescopic OTA is due to its less complex structure which consumes less amount of area, consumes less power and provides high speed of operation. Simulation results verified that KHN filter designing using Telescopic OTA provides high amount of controllability of circuit parameters as compared to current conveyor and op-amp based KHN filter.

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