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THE DESIGN OF OTA-C FILTER BASED ON THE PROTOTYPE OF LADDER LC FILTER

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ABSTRACT

The article discusses the design method of operational trans-conductance amplifier-C(OTA-C) filter based on the prototype of LC filter. It gives the OTA circuit used in the filter. And it makes a detailed analysis on characteristics of OTA. A third order OTA-C filter is presented. Its cut-off frequencies can be tuned by the bias DC current of OTA. The filter is easy to integrate. The proposed OTA has been simulated in CMOS technology. Simulation results show that the repose of the OTA-C filter and passive LC filter is almost the same. And it can be used in middle to high frequency circuit.

Keywords: *OTA-C filter, OTA, Ladder, LC Filter*

1. INTRODUCTION

There are many design methods of continuous-time filter, such as RC filters, MOSFET-C filters, Gm-C filters, Gm-C-the OP-AMP filter. In such many filters, there are three main types of high-performance continuous-time filters, active RC filters, MOSFET-C filter, and trans-conductance capacitor (Gm-C) filters. They generally use the MOS, Bi-CMOS technology, and the bipolar transistor [1].

Operational trans-conductance amplifier (OTA) as a basic active component is widely used in network synthesis. The OTA can constitute resistance, analog gyrator, inductance and frequency-dependent negative resistor (FDNR) and so on. The active OTA-C filters consist of these basic elements. Operational trans-conductance amplifier OTA has the following characteristics: Input voltage controls the output current; the gain is the trans-conductance; input stage using the bias, changing the external bias current (voltage) can adjust the gain of OTA; and can design a multi-input multi-output filter [2].The design parameters are the capacitors and the trans-conductance gains. This element is particularly suitable for the realization of fully integrated continuous time filters [3, 4, 5].

TA-C filter has many design methods. Two main methods are: (1) Based on the prototype of passive ladder network [6, 7] or directly integrated [8, 9]; (2) biquadratic second order section cascade[10, 11]. This paper the design method of operational trans-conductance amplifier-C (OTA-C) filter based on the prototype of ladder LC filter. The following example shows how to realize the third low pass elliptic filter.

The arrangement of the paper is as follows. Introduction elaborates in section-1. Section-2 describes the realization of OTA-C filter, the design of OTA is explained in section-3, the simulation is shown in section-4, and finally, the conclusion is given in section-5.

2. THE REALIZATION OF OTA-C ANALOG FILTER

First, according to the design requirements, the prototype of the passive LC ladder filter is obtained, and then uses the OTAs and capacitors instead of the resistors, inductors, and the frequency dependent negative resistance.

For example, the prototype of a third Passive low pass elliptic RLC filter shows in Fig 1.

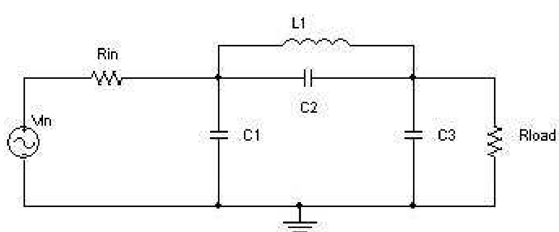

Fig 1: Third Passive Low Pass Elliptic RLC Filter

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The left part of Fig. 1 contains the power and resistor. The form of OTA-C is shown in Fig 2.

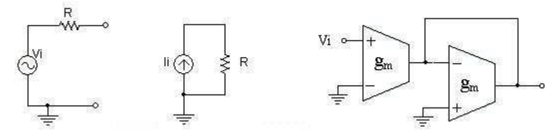

Fig 2: The Form of OTA-C to the Left Part of Fig 1

Floating inductor can use the following OTA-C circuit form, and is shown in Fig 3.

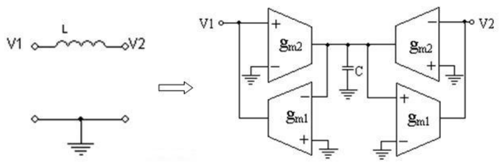

Fig 3: The Form of OTA-C to Floating Inductor

Based on Fig 1, it can obtain the form of the OTA-C circuit. It is shown in Fig 4.

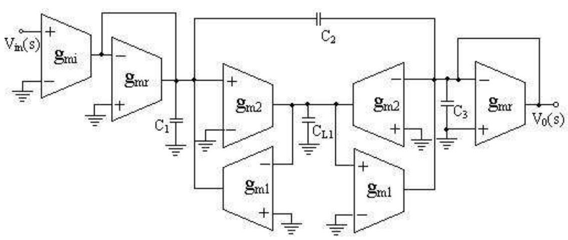

Fig 4: The OTA-C filter Based on Fig 1

From the above example, it can be seen that the RLC passive ladder filter can easily get the form of OTA-C filter. It can realize any higher order transfer functions. But when the order is very high, it contains a lot of active components, so the circuit is more complex.

3. THE REALIZATION OF OTA-C ANALOG FILTER

A prototype of RLC passive ladder filter can transform into the OTA-C filter. However, all of the OTA is nearly the OTA macro model, rather than use the transistor circuit. Thus the design of OTA is very important. It gives an OTA circuit, and use the OTA unit to design the OTA-C analog filter.

The design of OTA affects the performance of filter. The design methods of OTA are varied, but it is as far as possible to improve the OTA linear range. The OTA circuit is shown in Fig 5.

The main advantage of the OTA circuit is that the input signal is a differential form, but its drawback id the output voltage may be unstable. Thus it needs a common mode feedback circuit.

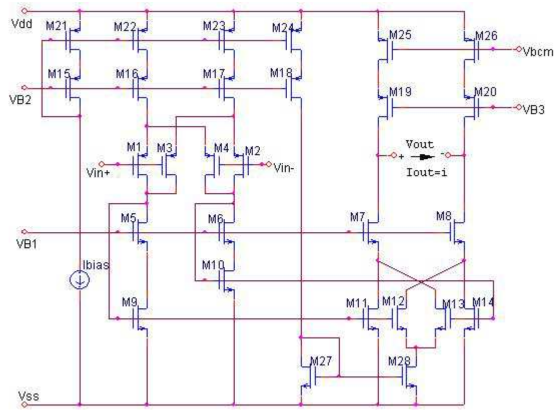

Fig 5: The OTA Circuit

In the design of trans-conductance integrator output, the feedback circuit form is shown in Fig 6. Comparing the sum of the output voltage with common-mode reference voltage, the common mode feedback voltage controls common-mode output voltage of Gm-C integrator.

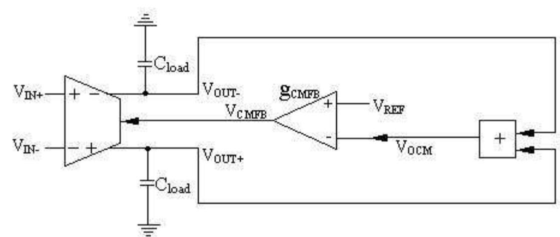

Fig 6: The Functional Block Diagram of Common Mode Feedback Circuit

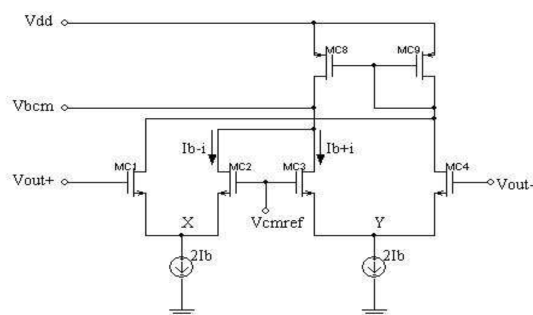

Fig 7: The Diagram of Common Mode Feedback Circuit

In Fig 7, V_{out+} and V_{out-} are connected to the output of the differential OTA. In the ideal case, their amplitudes are equal and opposite in sign. Therefore, the voltages of the differential pair are equal. The current of MC1 equals to the current of MC3, the currents of MC2 and MC4 are equal.

Assume that the current of MC2 is : $I_{d2} = I_b - i$, $2I_b$ is bias current of differential pair, i is the changing current of Id2, then the current in MC3 is

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$I_{d3} = I_b + i$. The current of MC8 is $I_{d8} = I_{d2} + I_{d3} == I_b + i + I_b - i = 2I_b$.

Therefore, as long as the common-mode voltage V_{out+} and V_{out-} are equal, the current of MC8 is constant. Even if the voltage of differential pair is very large, the current is constant, still equal to $2I_b$. Accordingly, the bias voltage of the trans-conductance output stage is controlled by voltage Vbcm. This indicates that the bias current of the output is equal when there is no common-mode voltage. The voltages in the X and Y point will follow V_{out+} and V_{out-} . Therefore, the bias current is unlikely to be constant. However, with a first order approximation, it still can be considered that the currents of MC8 and MC9 are almost constant.

Now, it assumes that the common-mode voltage changes, for example, it increases a little. The change in the voltage will cause the currents in MC2 and MC3 are reduced. So the current of MC8 is reduced, and the gate voltage of MC8 increases. This voltage is to maintain the output current source remains unchanged. However, when the gate voltage of MC8 increases, the current source is reduced, then the common mode voltage is reduced, thereby compensating for the increase of the common mode voltage.

If the effective gate-source voltage range of the differential transistor pair is very large, then input voltage of common mode feedback circuit is very large. However, the linearity of common-mode feedback circuit limits the range of the differential output voltage.

In our design of OTA, the common-mode feedback circuit is shown in Fig 8.

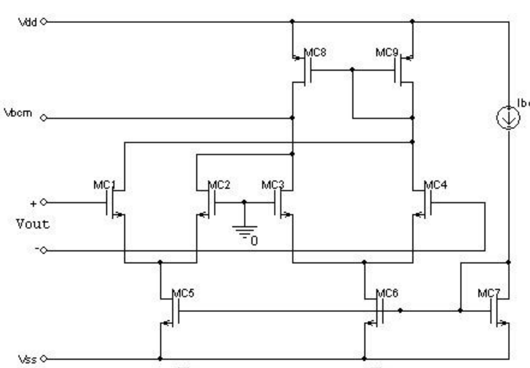

Fig 8: The Actual Common Mode Feedback Circuit

An important parameter of OTA is the tune range of trans-conductance. It determines the tune range of the OTA-C filters. Fig 9 is the measurement of OTA trans-conductance with frequency. Fig 10 is the measurement of OTA trans-conductance with voltage variation.

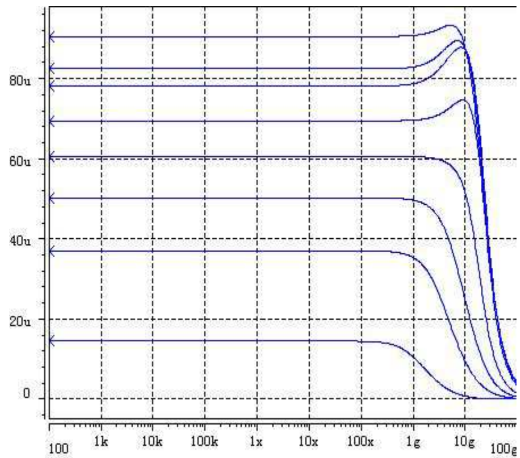

Fig 9: OTA Trans-conductance Change with Frequency

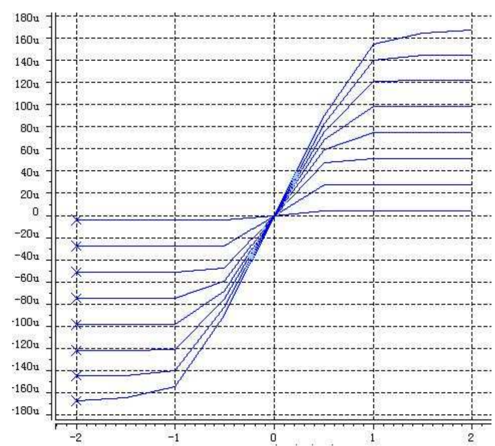

Fig 10: OTA Trans-conductance Change with Voltage

4. DESIGN EXAMPLE WITH OTA

Designing a third order elliptic filter, the cut off frequency of the filter is 5 MHz, and the pass-band gain is 0dB, band ripple is 1dB, the stop-band attenuation is 40dB. The passive RLC ladder filter is shown in Fig 1.

Where Rin=Rload=20k Ω , C1=3.039pF , C2=0.2313pF, L1=575.6uH, C3=3.039pF.

The passive RLC filter convert to the OTA-C filter circuit shown in Fig 11.

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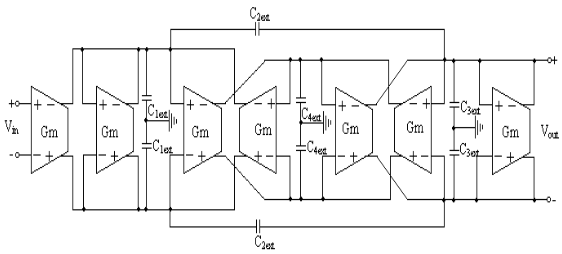

Fig 11: The Third Order Elliptic OTA-C Filter

Where C1ext=3.039pF， C2ext=0.2313pF， C3ext=3.039pF，C4ext=1.439pF.

The response of passive RLC filter Fig 1 is shown in Fig 12. When the OTA uses the Fig 5, the OTA-C filter response of Fig 11 is shown in Fig 13.

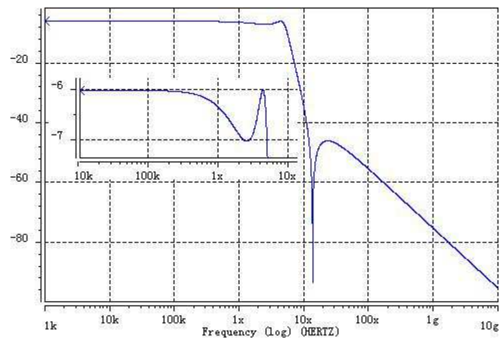

Fig 12: The Response of Passive RLC Filter

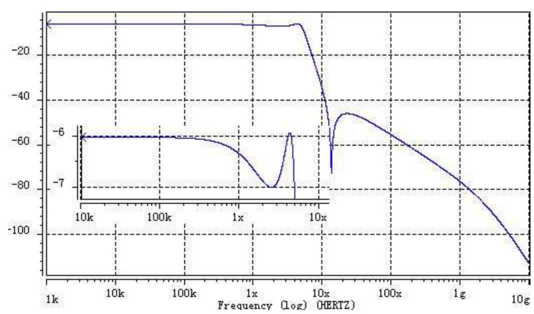

Fig 13: The Response of OTA-C Filter

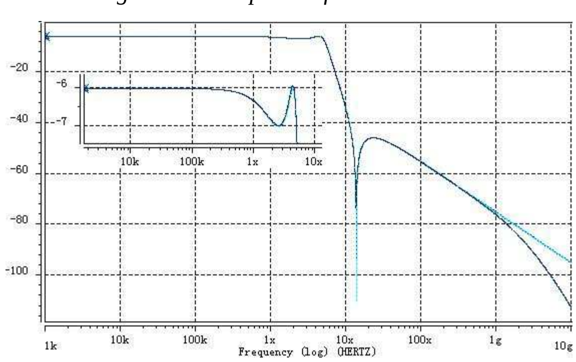

Fig 14: The Comparison Between the Fig 12 and Fig 13

In the same coordinate, the comparison is made between the response of Fig 12 and Fig 13, shown in Fig 14. It can be seen that the response of passive RLC filter and the OTA-C filter are almost identical. So it can design the OTA-C filter based on based on the prototype of LC filter.

The trans-conductance of OTA changing with the bias current Ibcm of OTA, and thereby the cutoff frequency of OTA-C filter changes. The bias current or voltage can change the cutoff frequency continuously, and this reduces the cost. When changing the bias current Ibcm, the filter response is shown in Fig 15.

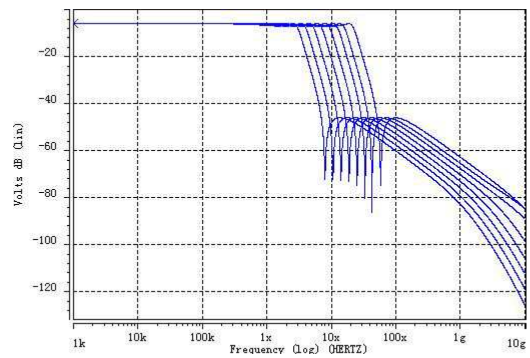

Fig 15: The Filter Response when Changing the Bias Current Ibcm of OTA

5. CONCLUSIONS

The article discusses the design method of OTA-C filter based on the prototype of LC filter. The OTA-C filer can be easily change the cutoff frequency by changing the bias current Ibcm of OTA. The simulation results show that the repose of the OTA-C filter and passive RLC filter is almost identical. The filter can be used in middle to high frequency application.

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