A bicmos Gm-C bandpass filter with Q enhancement based on symbolic design.

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Abstract The utility and importance of symbolic analysis is well known in our area, i.e. Control Theory is not conceived without Mason's Rule. This article remarks this importance with some novel applications. Basic applications are exposed, general filters based on OTA (Transconductance Operational Amplifiers) *Gm-C* applications are also presented, the article finishes with a Q enhancement filter design using this technique. A new design was achieved for a second order bandpass filter (*Gm-C*), *Q* enhancement using OTAs and a single one way feedback path stage. TopSpice and Matlab results are also presented.

Key words: Symbolic design, Mason's rule, Transconductance Oerational Amplifiers, OTA's, bandpass filter, Q quality factor, Gm-C.

1 Introduction

Let's focus our attention to the second order *gm-C* bandpass filter in Fig. 1, which has been built from the conventional biquad structure.

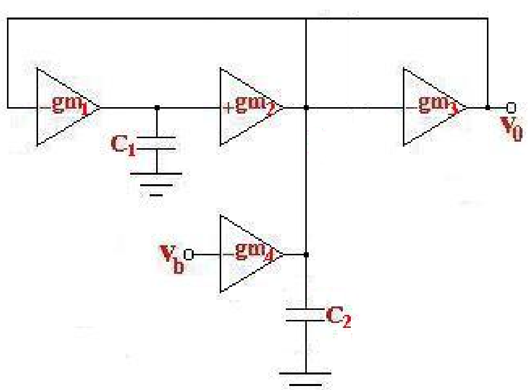


Fig. 1 .*The second order gm-C bandpass filter.*

The current-voltage expressions are:

$$I_{C1} = -gm_1 V_{C2} \qquad (1)$$
$$V_{C1} = I_{C1}/sC_1 \qquad (2)$$

$$I_{C2} = gm_2 V_{C1} - gm_3 V_{C2} + gm_4 V_i \qquad (3)$$

$$V_{C2} = I_{C2}/sC_2 \qquad (4)$$

$$V_0 = V_{C2} \qquad (5)$$

Where the gm's corresponds to the transconductance of each stage, we draw the corresponding signal flow graph (*SFG*) of the system ilustrated above. Fig. 2 shows the signal flow graph of the second order *gm-C* bandpass filter.

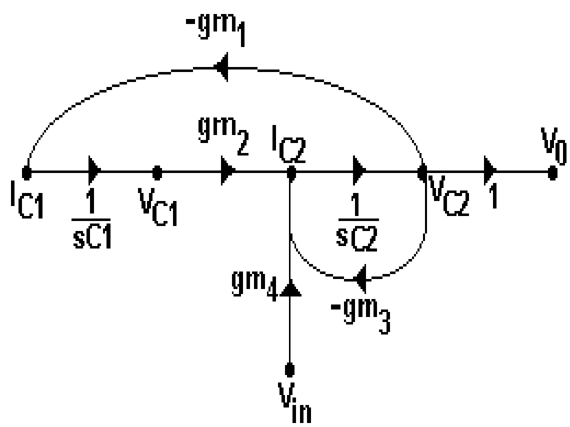


Fig. 2. *SFG corresponding to the second order gm-C bandpass filter.*

Aplying Mason's rule the transfer function is obtained,.

$$T(s) = K \frac{\frac{gm_4}{C_2} s}{s^2 + \frac{gm_3}{C_2} s + \frac{gm_1 gm_2}{C_1 C_2}} \quad (6)$$

from this expression :

$$K = 1 \quad (7)$$

$$a_1 = \frac{gm_4}{C_2} \quad (8)$$

$$\omega_0 = \sqrt{\frac{gm_1 gm_2}{C_1 C_2}} \quad (9)$$

$$Q = \sqrt{\frac{C_2}{C_1}} \cdot \frac{\sqrt{gm_1 gm_2}}{gm_3} \quad (10)$$

Where K is the gain, a_1 the coeficient of the zero in the filter, ω_0 the middle frequency and Q the selectivity factor

It is clear that important parameters of the filter such as selectivity and middle frequency are determinated by transconductances and load capacitances in the system. Due to this, manipulations in the values of those parameters can be done to specify the Q of the filter. In a monolithic realization transconductances as well as capacitances depend on many factors i.e. the technology, and therefore they are manufacture processing and aging dependents, independently of the process characteristics, we look for another way to enhance the Q quality factor.

2 The use of symbolic design to enhance the Q of the filter.

We need to identify in the *SFG* of the filter the way in which ratios (7) - (10) are determinated. Fig. 3 shows the two cascaded integrator in the SFG of the biquad filter.

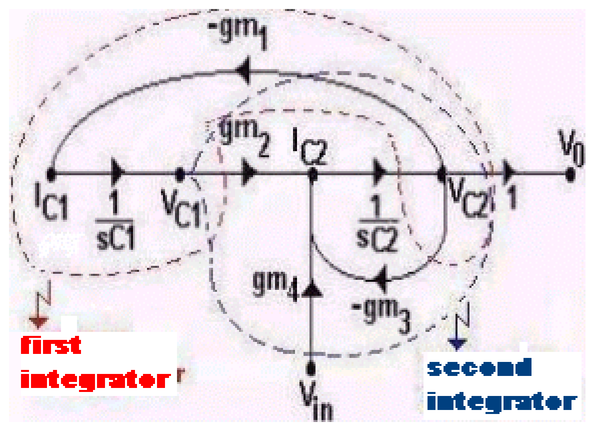


Fig. 3. *The elements in the SFG of the biquad gm-C bandpss filer.*

Mason's rule applied in this case shows that the first order factor in the transfer function's denominator polynomial is given by the second integrator closed loop gains product of the fig. 3. So, in order to enhance the Q of the filter we need to manipulate the *SFG* in such a way that the first order coefficient of the transfer function allow us to add a multiple factor that enhances the Q quality factor. According to this fact, we add a special feedback loop.

Fig. 4 presents a new *SFG* of the second order *gm-C* bandpass. A one way feedback loop has been added.

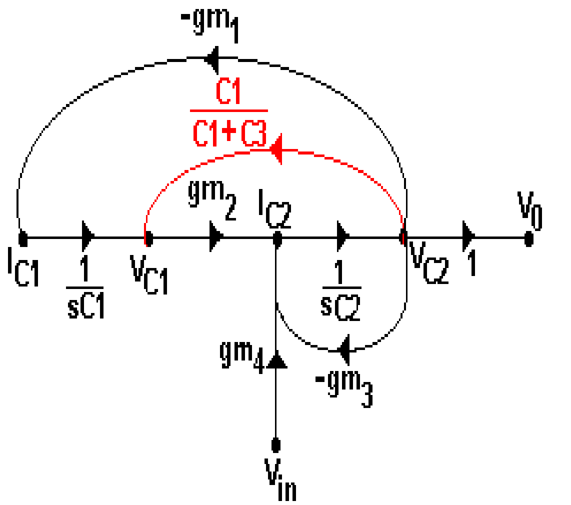


Fig.4 .*The new SFG of the second order gm-C bandpass filter.*

We can appreciate in fig. 4 that the feedback loop (red) has special properties, it is a feedback loop that samples only voltage and feeds only voltage through a capacitive voltage divider, brought up by the first integrator load and the inclusion of C_3. An only voltage feedback is needed because otherwise another transconductance amplifier must be included. This new feedback loop alters the relationship between the first and second integrator in the original *SFG*, the gain loop transfer ratio from I_{C1} to V_{C1} changes.

Aplying Mason's rule to the *SFG* of the fig. 4, we have

$$T(s)=\frac{\frac{gm_4}{C_2}s}{s^2+\frac{gm_3C_1+(gm_3-gm_2)C_1}{C_2(C_1+C_3)}s+\frac{gm_1gm_2}{(C_1+C_3)C_2}} \qquad (11)$$

Now we set $gm_4=gm_3=gm_2=gm_1=gm$ and $C_2=C_1+C_3$ to obtain

$$T(s)=\frac{\frac{gm}{C_1+C_3}s}{s^2+\frac{gmC_1}{(C_1+C_3)^2}s+\frac{gm^2}{(C_1+C_3)^2}} \qquad (12)$$

And finally the middle frequency and the selectivity parameters of the filter are now expressed by

$$Q=\frac{(C_1+C_3)}{C_1} \qquad (13)$$

$$\omega_0=\frac{gm}{C_1+C_3} \qquad (14)$$

Taking care in the selection of the capacitance values we are able to achieve Q enhancement bandpass filters more selective than conventional structures.

3 A new Gm-C structure of a biquad banpass filter.

A first approach to obtain an a circuit that performs the same function as the symbolic diagram is shown next in fig. 5., It is a *gm-C* bandpass filter type as in the previous case

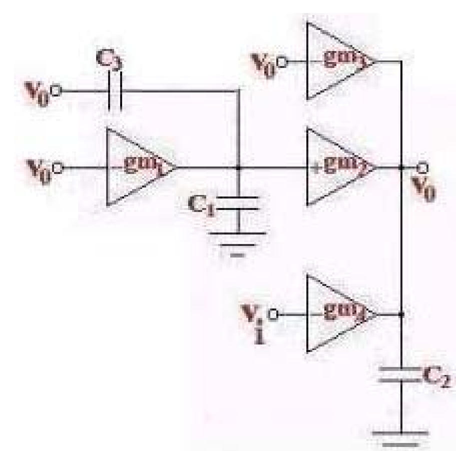


Fig. 5. *A new circuit obtained from the symbolic design.*

Fig. 5 shows a circuit where there are multiple feedback trajectories from the output voltage. However, the *SFG* proposed in fig. 4 conditionates the added feedback loop to be an only voltage feedback loop, this feature is translated to an awesome result: the feedback loop has to be unidirectional in the path from the output voltage to the first integrator load. A floating capacitance between the output node and the first integrator load node is not allowed to be interconnected, actually an element with the features showed in fig. 6, must be added .

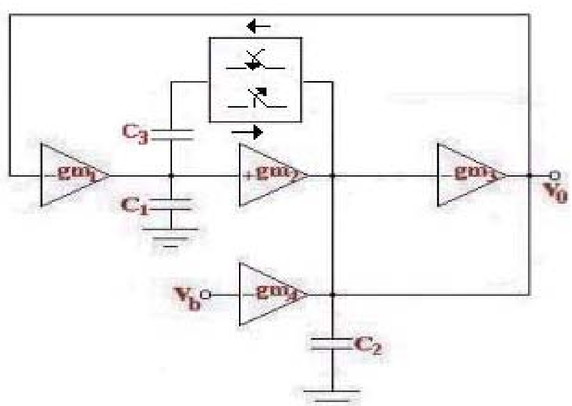


Fig. 6 *A second approach to a new electric diagram obtained from the use of symbolic design.*

The inclusión of an operational amplifier (OPAM) to carry out the conditions set by the design results in a novel circuit of a biquad *gm-C* bandpass filter, it is shown in fig. 7.

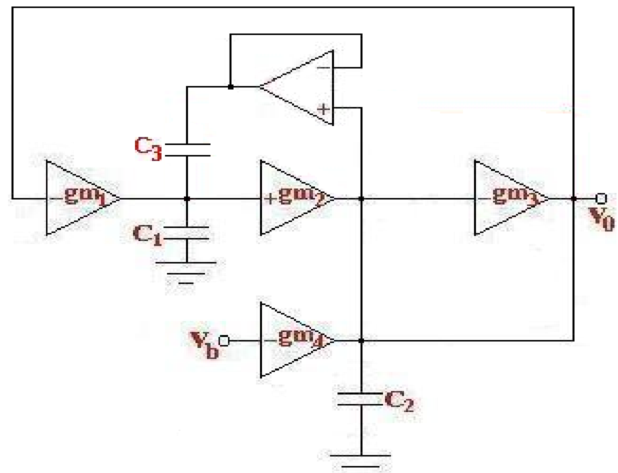


Fig. 7. *A new circuit to obtain a Q enhancement biquad gm-C bandpass filter .*

4 A bicmos Gm-C filter with Q enhancement based on symbolic design.

Biquad bandpass filter based on symbolic design and a conventional *gm-C* filter are designed to be compared. Both types of structures will have the same capacitances and transconductance values.

First, we need to emulate our systems in order to get all the possible information and features of both filters such as, the gain (G), bandwidth (BW) and output and input impedances of the amplifiers to avoid undesirable behavior. MATLAB results are presented in fig. 8. they show the emulation of both systems: the proposed and the conventional one for a middle frequency ω_0=1.6 MHZ, a *Q* of 50 is obtained with the proposed design compared with Q=1 of the conventional type.

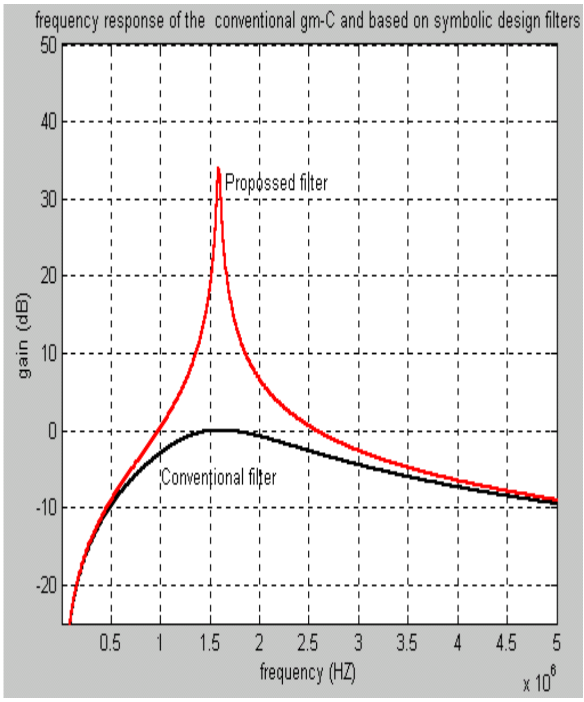


Fig. 8 *MATLAB results obtained from the emulation of both systems: the proposed filter (red mark) and the conventional filter (black mark)*

The results obtained from emulation indicates that transconductance amplifiers must have high input and output impedances, an amplifier whose gain-bandwidth product (GBW) will be wide spread enough for a gain above 30dB.

The Miller structures showed in fig. 9 presents the operational transconductance amplifier (OTA) used to implement the filters.

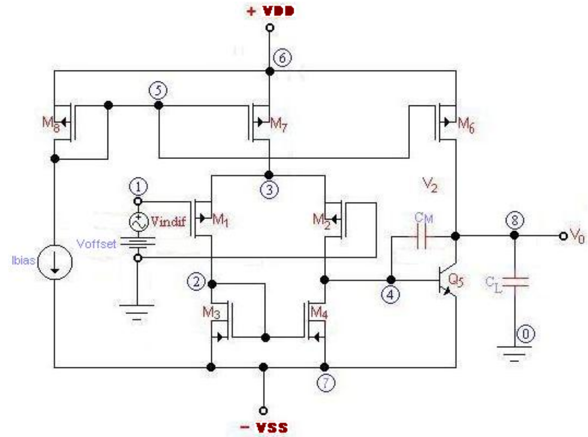


Fig. 9. *OTA used to implement the filters.*

Simulated results were obtained using 0.35um length channel and lateral bipolar AMS manufacture processing specifications. TOPSPICE results of the OTA are presented in fig. 10.

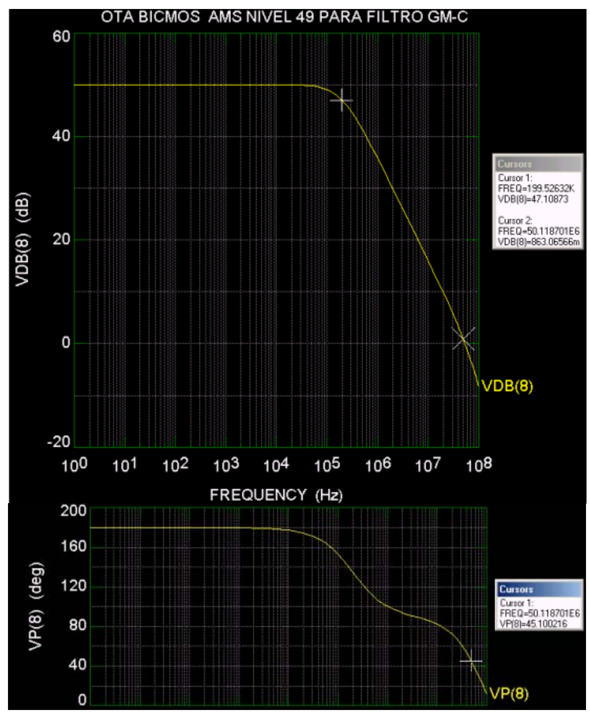


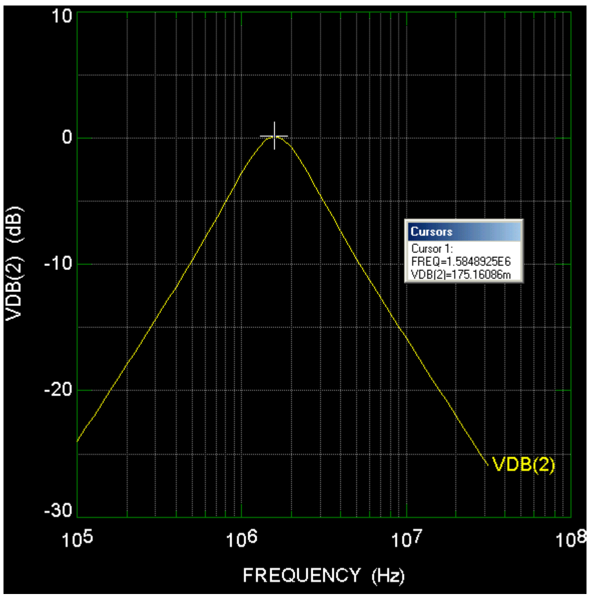
Fig. 10. *Frequency response and phase margin of the OTA .*

We can appreciate that the OTA has a DC gain of 50dB, a three db band width (BW) of 199KHZ, a gain bandwidth product

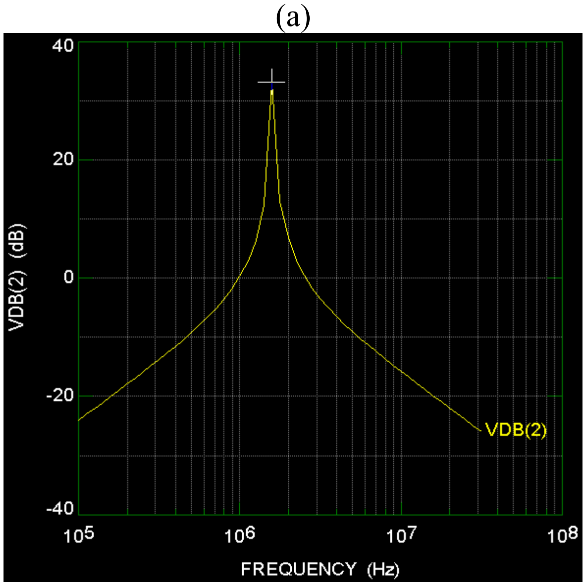
(GBW) of 50MHZ and a phase margin of 45^0.

5 Simulation results.

Fig. 11 shows SPICE results of both filtering systems: the conventional and the proposed one



(a)



(b)

Fig. 11. *SPICE results of the filters: (a) conventional filter gm-C and (b) propossed filter based on symbolic design*

The Q on the conventional design is 1 and in the proposed filter is 50, both filters were implemented with the same capacitance load values and transconductance values, both filters have a central frequency of 1.59MHZ.

6 Conclusions

A new Gm-C band pass filter with Q enhancement was designed based on a symbolic analysis and design.

It is not the only implementation, new feedback topologies can be used, other concepts like single direction pads can further be investigated.

It permits a global design using different tools like Matlab and Spice programs.

The performance of the simulated proposed filter seems to be better than the conventional ones.

Synthesis of circuits derived from a symbolic structure shows different solutions to traditional systems, digital implementations are also being studied.

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