DESIGN OF DIFFERENTIAL TYPE CLASS-AB GENERAL NOTCH FILTER IN THE LOG DOMAIN

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ABSTRACT

In this study, a current-mode second-order differential type Class AB notch filter has been synthesized in the Log domain. In the proposed filter only transistors, capacitors and current sources are required to realize a filter function. Pole frequency ω_0 of the designed filter can be electronically tuned by changing the I_f current. The proposed circuit is simulated in PSpice by using CBIC-R type transistor models. The pole frequency of the filter can be changed between 300 kHz to 3 MHz. For regular notch filter, low-pass notch filter and high-pass notch filter, it has been shown that maximum attenuation obtained is about 85 dB, 65 dB and 77 dB respectively. In addition to these simulations, time domain, THD and noise analysis are carried out. The obtained results are given.

I. INTRODUCTION

Log domain filters are new members of current mode active continuous time filters family [1,2]. Log domain filters, more generally ELIN filters, are suitable for low voltage and low power applications, have a large dynamic range and works at high frequencies. Additionally, these filters are highly linear, i.e. produce low distortion, and can be electronically tunable [2, 3]. Many researchers have interested in these advantages of Log domain filters [4-15]. Only transistors, capacitors and current sources are required to design this type of filters [7, 8].

Designing Class AB circuit is an efficient approach for balancing the need for good linearity, low noise, and low power consumption. A Class AB circuit is a combination of Class A and Class B. After development of the general theory of Class AB filters in the Log domain [8-9], many researchers presented their studies on Class AB Log domain filters [4, 9-13].

Generally, two methods are used for synthesis of Log domain filters: State-space synthesis method and signal flow synthesis method. State-space synthesis method is a very powerful and efficient approach in the synthesis of Log domain filters [1]. In this method, more mathematical operations are needed. On the other hand, it gives opportunity for detailed analysis as it satisfies checking of the elements of the circuit [8].

In this study, differential type, Class AB, second order notch filter is synthesized in the Log domain. The design is based on the state space synthesis method. The proposed filter is simulated in PSpice for various frequency, I_f and Q quality factor values. Time domain and frequency domain results are given and the results are discussed.

II. SYNTHESIS

State-space synthesis method provides a very general solution for realizing filter function [2,7]. Log domain filters can be described as a nonlinear mapping on the state variables of state space description of a particular transfer function. To implement the filter, state equations have to be further transformed to nodal equations at the nodes of grounded capacitors [9].

In the differential type Class AB Log domain state space synthesis method [7], state space variables x's and the input current u are split into two parts which are named as 'L' and 'R' in order to operate as differential type Class AB. Relationship of L, R and origin signals are shown in Equation 1.

$$\begin{aligned} x &= x_L - x_R \\ u &= u_L - u_R \\ y &= y_L - y_R \end{aligned} \tag{1}$$

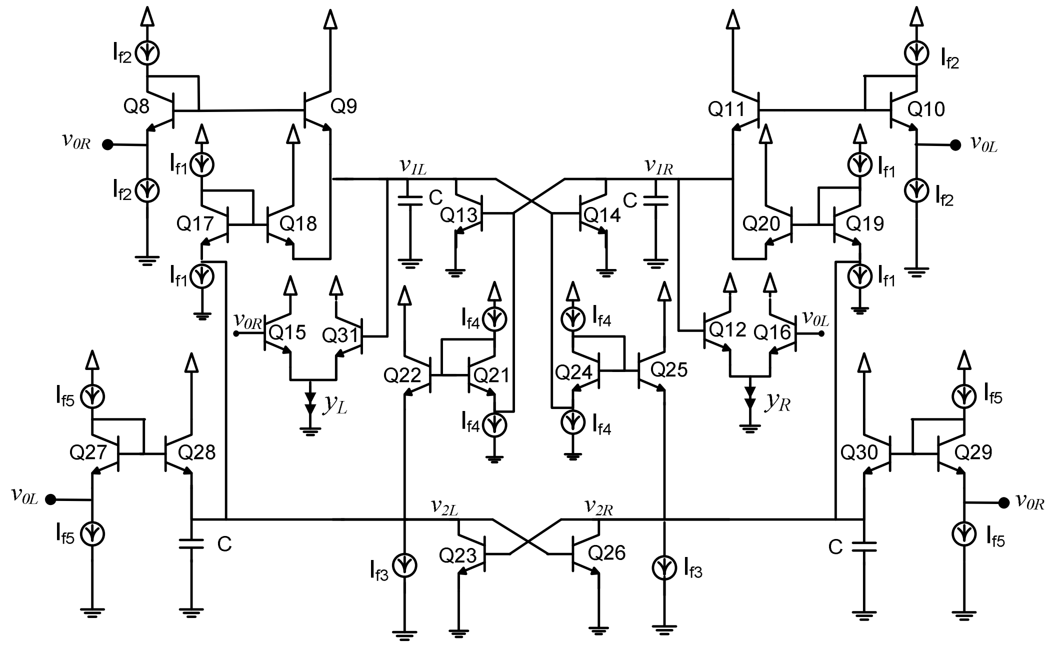

Figure 1: The proposed notch filter circuitry

Difference of input values for *L* and *R* sides is equal to the input and their respective values are strictly positive for all possible inputs. Input splitter circuit [8] used in this study to obtain proper input signals for Class AB operation is shown in Figure 2.

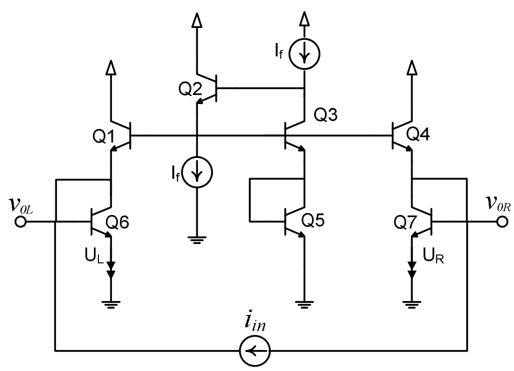

Figure 2: The current splitter circuitry

For Class AB differential type Log domain circuits, both *L* and *R* sides have the same architecture and input signals of those have the same signal only with phase difference, which yields in equilibrium balance in signal process. This allows a lower total harmonic distortion compared to classical Class AB circuits [4, 7-9].

A second-order notch filter transfer function can be written as fallows;

$$H(s) = \frac{I_{out}(s)}{I_{in}(s)} = a_2 \frac{s^2 + \omega_n^{\ 2}}{s^2 + s\frac{\omega_0}{Q} + \omega_0^{\ 2}} \quad (2)$$

where ω_0 is the cut off frequency and Q is the quality factor of the filter. First of all, a proper state space representation of this transfer function is obtained from Equation 2. After nonlinear mapping of Equation 3 and some manipulation, equations for left part of the circuit are obtained as shown in Equation 4. Equations for the right part are obtained in a similar way.

$$\begin{aligned} x_L &= I_S\, e^{\frac{v_L}{V_T}} \\ u_L &= I_s\, e^{\frac{v_{0L}}{V_T}} \end{aligned} \quad (3)$$

$$C\dot{v}_{1L} = I_s e^{\frac{(v_{2L}+V_{f1}-v_{1L})}{V_T}} + I_s e^{\frac{(v_{0R}+V_{f2}-v_{1L})}{V_T}} - I_s e^{\frac{v_{1R}}{V_T}} \quad (4.a)$$

$$C\dot{v}_{2L} = -I_{f3} + I_s e^{\frac{(v_{1R}+V_{f4}-v_{2L})}{V_T}} + I_s e^{\frac{(v_{0L}+V_{f5}-v_{2L})}{V_T}} - I_s e^{\frac{v_{2R}}{V_T}} \quad (4.b)$$

$$y_L = I_s e^{\frac{v_{1L}}{V_T}} + a_2 I_s e^{\frac{v_{0R}}{V_T}} \quad (4.c)$$

Equation (4.a) can be considered as a node equation for a grounded capacitor's node. Dot above the voltage term in the left side depicts derivative by time. If C is assumed to be the value of a capacitance, then Equation (4) a formulates the capacitor's current. The right side terms depict transistor currents that those of base voltages are tied to $(v_{2L}-v_{1L})$, $(v_{0R}-v_{1L})$ and v_{1R} voltages respectively. Carrying out same operations for Equations (4.b, 4.c), differential type Class AB notch filter designed in Log domain is obtained and shown in Figure 1.

III. SIMULATION RESULTS

The proposed notch filter was simulated by using CBIC-R transistors with PSpice simulation program. The circuit parameters are chosen as a_2=1, V_{cc}=3V, C=500pF. The value of I_f is swept from 25µA to 240µA in order to tune the pole frequency of the filter. Therefore, the natural frequency of the filter is tuned between 300 kHz and 3 MHz and the corresponding frequency response is shown in Figure 3.

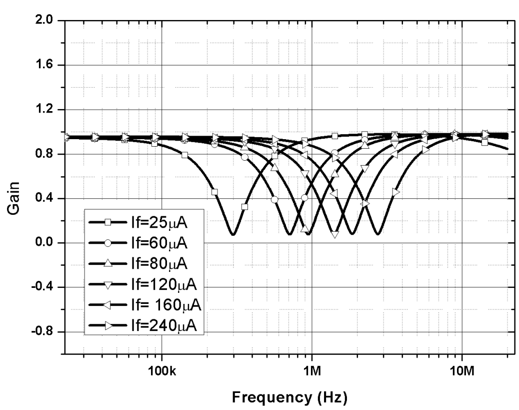

Figure 3: Tunable frequency responses for the proposed notch filter

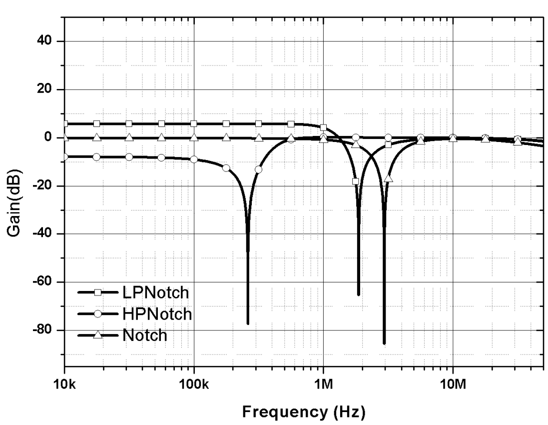

Figure 4: Frequency responses for high-pass notch, low-pass notch and notch filters

Changing the values of current sources, all three notch filter responses can be obtained. To demonstrate this property, series of simulations are carried out and low pass notch, regular notch and high pass notch responses are depicted in Figure 4. It is shown that DC gain of the filter determines the type of notch filter. Low-pass notch, notch and high pass notch responses are obtained for gains of low DC, 0 dB and high DC respectively. According to PSpice analysis of designed filter, maximum attenuation values obtained for low pass notch, regular notch, and high pass notch are 65 dB, 85 dB and 77 dB respectively.

For the time domain analysis, the circuit was set to a 1 MHz pole frequency, quality factor of Q=1 with I_f =600µA. The transistor currents of the input splitter circuitry were also set to I_{in}= 100µA. Then, a sinusoidal signal applied to input with a 2, 6, 8, 10, 14 and 16 times of I_{in} value. The output signal's THD was measured for each case. Time response for the second order electronically tunable Log domain notch filter for I_{in}=600µA and f_0=1MHz, is shown in Figure 5. The result for THD analysis is given in Table 1.

Noise analysis is also performed. The noise is demonstrated as shown filter characteristic with peak value $131.235\, pA/\sqrt{Hz}$ for I_f =27.6 µA.

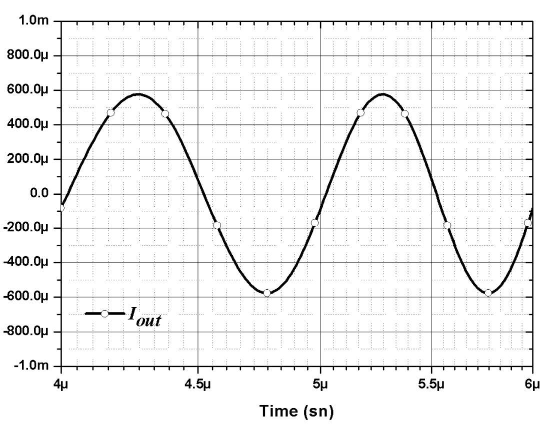

Figure 4: Time responses of proposed notch filter

Table1: Total harmonic distortion(%)

Input	Output(THD %)
200µA	0.0830
600µA	0.1700
800µA	0.2639
1mA	0.4084
1.4mA	0.7322
1.6mA	0.9128

IV. CONCLUSION

A current mode, second order differential type class AB Log domain notch filter is proposed in this study. The state space method is used in this study. Designed circuit's pole frequency ω_0 can be electronically tuned by changing the values of current sources. This filter circuit is simulated in PSpice by using CBIC-R type transistors. Both time domain and frequency domain results show that the designed filter takes advantages of the Class AB differential type Log domain circuit.

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REFERENCES

1. D. R. Frey, Log-Domain Filtering: An Approach to Current-Mode Filtering, IEE Proceedings-g, Vol. 140, No.6, pp. 406-416, December 1993.
2. D. R. Frey, Exponential State Space Filters: A Generic Current Mode Design Strategy, IEEE Trans. CAS-I: Fund. Theory and Appl., vol. 43, pp.34-42, 1996.
3. Y. Tsividis, Externally Linear, Time-invariant Systems and Their Application to Companding Signal Processors, IEEE Trans. Circuits and Syst.-II, vol. 44, no:2, pp.65-85, February 1997.
4. D.R. Frey, Current Mode Class AB Second Order Filter, Electronics Letter, vol.30, no.3, pp. 205-206, 3 February 1994.
5. D. Perry and G.W.Roberts, The Design of Log-Domain Filters Based on the Operational Simulation of LC Ladders, IEEE Transaction on Circuits and Systems-II: Analog and Digital Signal Processing, Vol. 43, 1996.
6. M. Punzerbeger and C. Enz, Log-Domain Filters for Low-Voltage Low-Power Applications, Proc. Int. Workshop Low Power RF Integrated Circ., 1999.
7. D. R. Frey and A. T. Tola, A State-Space Formulation for Externally Linear Class AB Dynamical Circuits, IEEE Transaction on Circuits and Systems-II: Analog and Digital Signal Processing, Vol. 46, pp.306-314, 1999.
8. A.T. Tola and D.R. Frey, A Study of Different Class AB Log Domain First Order Filters, Analog Integrated Circuits and Signal Processing, 22, pp.163-176, 2000.
9. A. T. Tola, A Study Of Nonideal Log Domain and Differential Class AB Filters, PhD. Dissertation, Lehigh University, 2000.
10. S. Surav Yılmaz, The Systematic Synthesis of Log-Domain Filters, in Turkish, MS Thesis, Pamukkale University, Denizli, 2005.
11. R. Arslanalp, The Realization of Elliptic Filters Approximation in the Log Domain, in Turkish, MS Thesis, Pamukkale University, Denizli, 2003.
12. M. Punzerberger and C. C. Enz, A 1.2 V Low-power BiCMOS Class AB Log-domain Filter, IEEE J.Solid State Circuits, vol. 32, no.12, pp. 1968-1978, December 1997.
13. A. T. Tola, R. Arslanalp, Ş. S. Yılmaz, Design of Current Mode, Low Voltage and Electronically Tunable Class AB Differantial Type KHN Filter in the Log Domain, in Turkish, Siu'05, Kayseri, 2005.
14. Yu, G. J., Chen, J.J., Lin, H.Y., Huagan, C.Y., A Low-Voltage Low-Power Log Domain Band-Pass Filter, International Symposium on VLSI Technology, Systems and Applications, 2003 pp.219-222.
15. A. Kirçay, U. Çam, State Space Synthesis of Current-Mode First-Order Log Domain Filters, Turk J. Electric Engineering, Vol. 14, No.3, pp. 399-416, 2006.