Log-domain low pass high pass first-order filter

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A new first-order log-domain filter topology implementing simultaneously low-pass (LP) and high-pass (HP) filter functions has been presented. The circuit employs log-domain cells, current sources and grounded capacitor. The circuit has simple architecture, wider dynamic range at low power supply and higher frequency operation as it is based on log-exponential relation of a transistor. The electronic tunability of the proposed filter and grounded capacitor make it suitable for construction in IC technology. The PSPICE simulations results are found to be in close conformity with the theoretical results.

Keywords: Log-domain filter, First-order filter, High frequency applicability

1 Introduction

Log-domain filters have received considerable attention due to their potential advantages over conventional continuous-time filters and as such a number of log-domain filters have been reported earlier. The log-domain filters are externally linear but internally highly non-linear. The processing of the signals by transistors in exponentially manner has made log-domain filters attractive. In these filters, the input current signal is first mapped using a natural logarithmic function. The resulting logarithmic signal is then processed in the log-domain, and the output is recovered using an exponential function to generate a current which is a linearly filtered version of the input. Mapping of the input current with the natural logarithm amounts to forcing the current through a diode, producing a voltage which is applied to the actual log filter. The log filter output voltage is mapped to a linear output current with an exponential function by applying this voltage to the base of a n-p-n transistor whose emitter is grounded and collector sinks the desired linear output current. The compression process can be performed by the log-in circuit shown in Fig. (1a & b) shows an exponential output circuit, known as log-out required to obtain linear response. Since the companding mapping is inverse, the overall response remains linear. Advantages of log-domain circuits over conventional continuous time filter circuits are inherent linearity without the need for negative feedback or degeneration; superior noise performance, improved high-frequency response, and wider operating bandwidth, due to the low impedances nodes along the signal path; low-voltage operation, since node-voltage swings are greatly reduced while currents, not limited by the supply voltage, can still have a large dynamic range; transconductance amplifiers employed in log domain filters are realized through employment of only a few transistors whereas the transconductance amplifiers which are designed for linear V-I characteristics used for developing conventional filters employs excessive transistors, resulting efficient possible circuit topology designs that have more bandwidth and consume less power in relation to the conventional filters; and use of grounded capacitors which are ideal for contemporary IC design techniques.  

Fig. 1— (a) Log-input circuit; (b) Log-output circuit
The idea of log-domain filtering was first initiated in 1979. A related concept exploiting companding technique was introduced in 1990. At the same time, the concept of current-mode companding was introduced. In 1993, a general procedure for the synthesis of biquadratic log-domain filters was developed and later, this technique was expanded to LC-ladder filters.

In this paper, a novel log-domain filter, realizing two first order filtering functions LP and HP simultaneously is presented. The circuit employs log-domain cells, current sources and grounded capacitor. The filtering parameters pole frequency and gain are electronically tunable independently but in a sequential manner through the bias currents. The circuit has been checked through PSPICE simulation and the results obtained are in close conformity with the theoretical results.

2 Circuit Description

The log-domain approach uses exponential current versus voltage characteristics of a transistor in which collector current is related to the base-emitter voltage by:

\[ I_C = I_S \exp \left( \frac{V_{be}}{V_T} \right) \]

or

\[ V_{be} = V_T \ln \left( \frac{I_C}{I_S} \right) \]

(1)

(2)

(3)

(4)

(5)

(6)

(7)

(8)

(where \( I_S \) is the saturation current, \( V_T = kT/q = 26 \text{ mV} \) at room temperature).

The inverting and non-inverting integrators used for the realization of the proposed filter depicted in Fig. 2, are respectively shown in Figs (3a & b). The current through the capacitor is given by:

\[ C \frac{dV_o}{dt} = I_o \exp \left[ \frac{V_{in} - V_o}{2V_T} \right] \]

The basic circuit used to develop log-domain LP and HP filter is shown in Fig. 2. A routine analysis of Fig. 2 yields the following current-mode transfer functions:

\[ T_{LP} = \frac{H}{s + \omega_o} \]

\[ T_{HP} = \frac{H}{s + \omega_o} \]

An inspection of the Eqs (3) and (4) reveals that the proposed filter realizes LP and HP transfer functions. The pole frequency \( \omega_o \), and gain \( H \) of the proposed filter in terms of bias current are as follows:

\[ \omega_o = \frac{1}{2V_TC} \left( \frac{I_{03}}{I_{02}} \right) \]

\[ f_o = \frac{1}{2\pi} \frac{1}{2V_TC} \left( \frac{I_{03}}{I_{04}} \right) \]

\[ H_{HP} = \frac{I_{01}}{I_{02}} \]

\[ H_{LP} = \frac{I_{01}}{I_{03}} \]

From Eqs (5)-(8), it is seen that the filter parameters are tunable through the respective biasing currents. The pole frequency \( \omega_o \) can be adjusted by \( I_{o2}, I_{o3} \) and \( I_{o4} \) and \( H_{LP} \) and \( H_{HP} \) can be tuned by \( I_{o1} \) without disturbing \( \omega_o \). Thus the circuit has independent programmable features.
3 Simulation Results
The proposed filter was simulated by using AT & T CBIC-R (NR200N-2X NPN), (PR200N-2X PNP) transistors to check the workability. The circuit was designed for a pole frequency of 1.59 MHz, $Q = 1$ and $H = 1$. This choice of parameters leads respectively to the values of capacitors and currents as $C = 200 \, \text{pF}$ and $I_{o1} = I_{o2} = I_{o3} = I_{o4} = 100 \, \mu\text{A}$ with $V_{cc} = 3\, \text{V}$. The current signals were taken along load resistor of 1 ohm. Figs (4a & b) depicts the simulation results of LP and HP signals. The tuning characteristics of gain and pole frequency for HP and LP filtering function was observed by varying respective bias currents. Figs (4c & d) depicts the variation of gain for LP and HP and Figs (4e & f) demonstrates the variation of frequency for LP and HP. The simulated results are in good conformity with the theoretical calculations.

![Fig. 4(a)—Simulation results of low pass log-domain filter](image1)

![Fig. 4(b)—Simulation results of high pass log-domain filter](image2)

![Fig. 4(c)—Variation of gain for different values of $I_{o1}$ for LP response](image3)

![Fig. 4(d)—Variation of gain for different values of $I_{o2}$ for HP response](image4)

![Fig. 4(e)—Variation of frequency for different values of $I_{o3}$ for LP response](image5)
4 Conclusions

A novel first-order LP and HP Log-domain filter is presented. The proposed filter is based on the integrator loops, current sources and grounded capacitors. The pole frequency $\omega_o$, gain $H$ are electronically and independently tunable through the respective bias currents. The PSPICE simulation results confirm the theoretical results.

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References