A NOVEL FIRST-ORDER LOG-DOMAIN ALLPASS FILTER

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ABSTRACT

This paper proposes a first order allpass log-domain filter, which is systematically derived using the state-space synthesis procedure. To the best knowledge of the authors, the filter is the first log-domain first-order allpass filter in the literature. The proposed filter has a simple structure and can be electronically tuned. It can operate at very high frequencies due to current-mode structure. PSPICE simulations are given to confirm the theoretical analysis.

I. INTRODUCTION

Log-domain filters are receiving interest in literature, mainly due to their suitability for low voltage, low power, large dynamic range, high frequency applications and electronically tunable. Most interesting of all, it opens the door to elegantly realizing linear system with inherently nonlinear (logarithmic-exponential) circuit building blocks. They have some additional advantages with respect to other filter implementation techniques; only transistors and capacitors are required to realize a filter function. The main concept is based on the exponential I–V characteristics of bipolar junction transistors (BJT) or the MOS transistor operating in the subthreshold region.

Adams introduced the idea of filtering in the log-domain in 1979 [1]. He proposed the first log-domain filter using log and anti-log techniques in conjunction with combination of forward-biased diodes and a capacitor to obtain a distortionless first order lowpass filter. A related concept using companding was introduced by Tsividis in 1990 [2]. At the same time, Seevinck independently reinvented the log-domain filter concept, which he denoted by the term current-mode companding [3]. In 1993, Frey presented his work, which shows that the synthesis of log-domain filters can be synthesized by state-space representation. For state-space synthesis method, the BJT can be directly used to realize the log-domain filters by mapping from state-space linear differential equations. He introduced a systematic state-space synthesis method for designing log-domain filters [4], [5]. Since then, many other researchers extensively investigated log-domain filters [6].

Up to now, several first order low-pass and high-pass log domain filters have been presented [6]. Furthermore, many biquadratic and high order log-domain filters are proposed in the literature. A literature survey shows that no any first-order log-domain allpass filters exist. On the other hand, allpass filters are one of the most important building blocks of many analog signal processing applications and therefore have received much attention. They are generally used for introducing a frequency dependent delay while keeping the amplitude of the input signal constant over the desired frequency range [7]. The purpose of this study is to propose a new log-domain first-order allpass filter.

II. THE PROPOSED FIRST-ORDER LOG-DOMAIN ALLPASS FILTER

A first-order allpass filter transfer function can be written as follows,

$$H(s)=\frac{Y(s)}{U(s)}=-a_1\frac{s-w_0}{s+w_0}\ ,\ a_1>0 \qquad (1)$$

where w_0 is the cut off frequency of filter. Here a_1 must be greater than zero otherwise this transfer function can not be realized with class-A filter type. Transfer function is transformed to the following equation:

$$\dot{y}=-w_0y+a_1w_0u-a_1\dot{u} \qquad (2)$$

Its state variables determined by using the companion form. In equation (2) derivative of input u is a drawback for realizing filter. The derivative of u must be eliminated from equation (2). State variable x is chosen as;

$$x=y+k_1u \qquad (3)$$

The equation (2) arranged to form the following equation,

$$\dot{x}=-w_0(x-k_1u)+a_1w_0u+(k_1-a_1)\dot{u} \qquad (4)$$

where k_1 is determined from equation (4),

$$k_1=a_1$$

When equation (2) is simplified and the derivative of u is eliminated, it can be derived that;

$$\dot{x}=-w_0x+2a_1w_0u \qquad (5)$$

The output equation is

$$y = x - a_1 u \tag{6}$$

where u is the input, y is the output and, x is the state variable. The equation (5) can be transformed into a set of nodal equations by using exponential mappings on the input and state variables. The following mappings can therefore be applied to quantities in equation (5), [5],

$$x = I_s e^{V_1/V_t}\ ,\ u = I_s e^{V_0/V_t} \tag{7}$$

I_s is the saturation current, V_t is the thermal voltage, $V_t = kT/q$. The derivative of u and x,

$$\dot{x} = I_s \frac{1}{V_t}\dot{V}_1 e^{V_1/V_t}\ ;\ \dot{u} = I_s \frac{1}{V_t}\dot{V}_0 e^{V_0/V_t} \tag{8}$$

The above relationship is applied to equation (5) and scaling factors are multiplied through the equation with $CV_t / I_s e^{V_1/V_t}$, then it is arranged to form the following nodal equation is;

$$C\dot{V}_1 = -w_0 CV_t + 2a_1 w_0 CV_t e^{\frac{V_0 - V_1}{V_t}} \tag{9}$$

where I_{f1} and I_{f2} are positive constants which are defined below equations,

$$I_{f1} = w_0 CV_t\ ,\ I_{f2} = 2a_1 w_0 CV_t \tag{10}$$

$$C\dot{V}_1 = -I_{f1} + I_{f2} e^{\frac{V_0 - V_1}{V_t}} \tag{11}$$

If I_{f2} is equal to $I_s e^{V_{f2}/V_t}$, the equation (11) can be arranged as,

$$C\dot{V}_1 = -I_{f1} + I_s e^{\frac{V_0 + V_{f2} - V_1}{V_t}} \tag{12}$$

The realization of the first order log-domain allpass filter circuit using the equation (12) is shown in Fig.1.

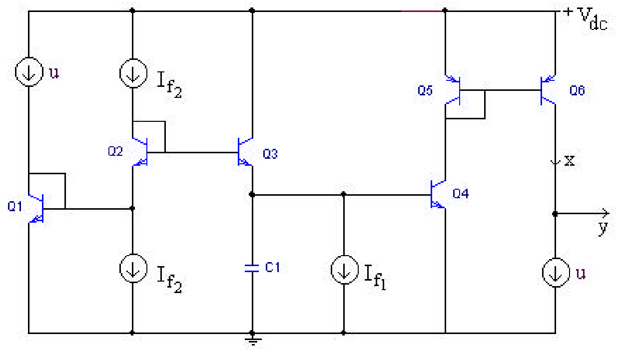

Figure 1. A first order log-domain allpass filter

The resonant frequency and the gain of filter are;

$$w_0 = I_{f1} / CV_t \tag{13}$$

$$a_1 = I_{f2} / 2w_0 CV_t \tag{14}$$

It should be noted that w_0 can electronically be tuned by changing I_{f1} and a_1 can electronically be also tuned by changing I_{f2}.

The proposed allpass filter has the following phase responses,

$$j(w) = -2\,\arctan\left(\frac{w}{w_0}\right) \tag{15}$$

Thus, the phase can be tuned by changing current I_{f1}.

III. SIMULATION RESULTS

The proposed filter was simulated by using both ideal and AT&T CBIC-R (NR200N-2X NPN), (PR200N-2X PNP) transistors. The circuit parameters are chosen as, $a_1 = 1$, $V_{CC} = 3V$, $I_{f1} = 100uA$, $I_{f2} = 200uA$, $C = 200pF$. The cut-off frequency of filter is $f_0 = 3MHz$. The gain and phase response of a first-order log-domain allpass filter are shown in Fig.2 and Fig.3, respectively. The tuning characteristics were observed by changing the external current in Fig.4. A Fig.5 shows the time-domain response of the filter. A sine-wave input at a frequency of $3MHz$ was applied to the filter. This causes a $86ns$ time delay at the output of the filter corresponding to 93^0 phase difference which is close to the theoretical value (90^0). Tolerable differences are observed that realization of this filter in simulation has provided satisfactory results.

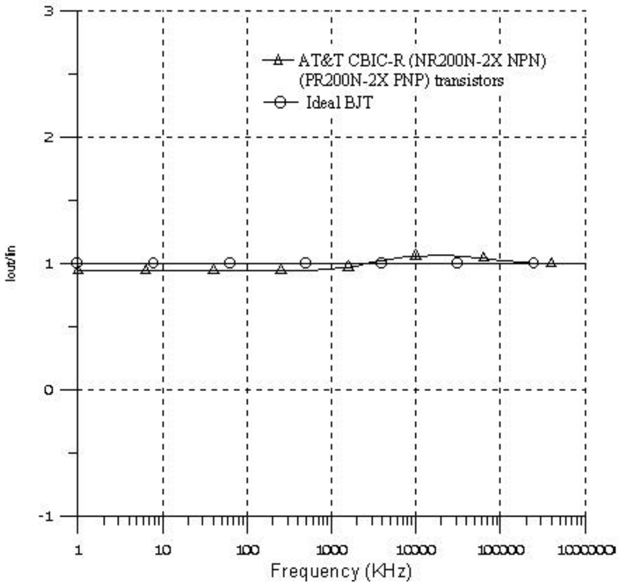

Figure 2. Gain response of first order log-domain allpass filter

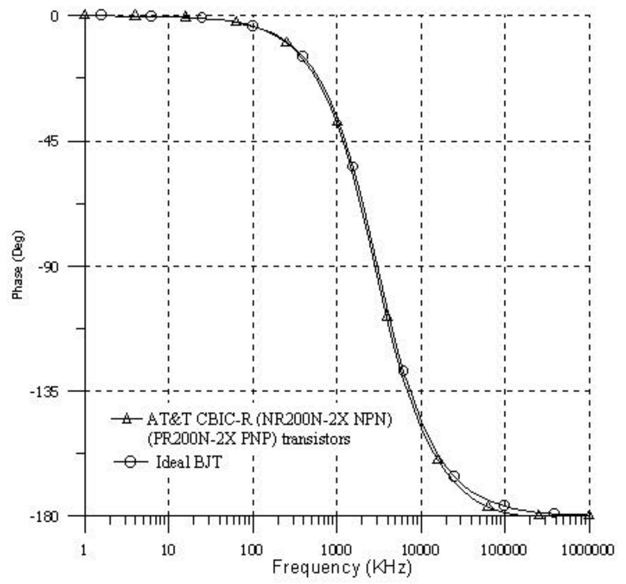

Figure 3. Phase response of first order log-domain allpass filter

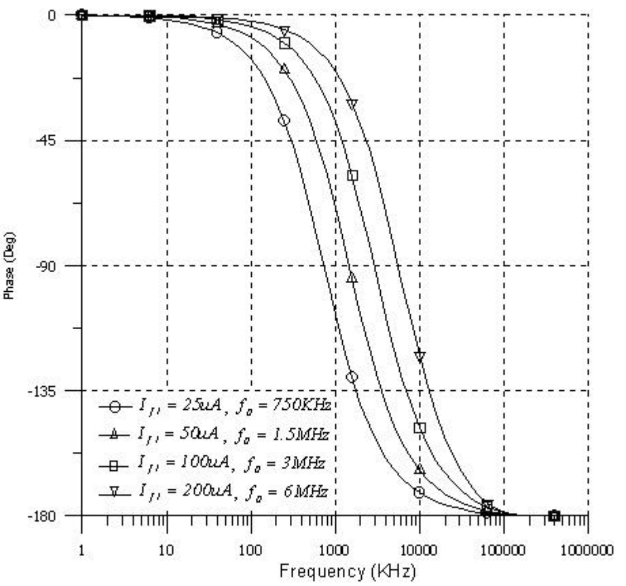

Figure 4. Tuning characteristics were observed by changing the current I_{f1}

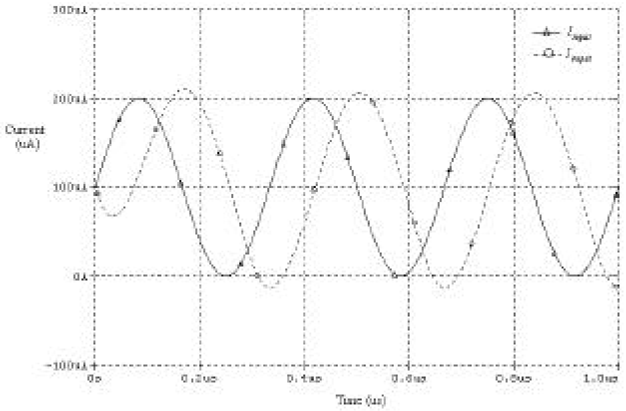

Figure 5. Time-domain response of the proposed allpass filter

IV. CONCLUSION

A novel first-order class-A log-domain allpass filter structure is presented. A systematic synthesis procedure to derive the filter circuit is also given. To the best knowledge of the authors, this is the first log-domain first-order allpass filter in the literature. PSPICE simulations are provided to confirm the theoretical analysis. The proposed filter has the following advantages:

- i) can be electronically tuned,
- ii) has a wide bandwidth,
- iii) employs only BJTs and capacitor,
- iv) has a very simple structure,
- v) suitable for VLSI (very large-scale integration) technologies.
- vi) suitable for low voltage/power applications.

The small deviations in the gain and frequency response from theoretical values are caused by the non-idealities of the BJT such as finite-beta, non-zero ohmic junction resistances, early voltages. It is expected that the proposed current-mode log-domain first-order allpass filter will be useful in the design of analog signal processing applications where phase or delay equalization is needed.

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