A DESIGN OF DIFFERANTIAL TYPE CLASS AB TOW-THOMAS FILTER IN THE LOG DOMAIN

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ABSTRACT

In this study, a current-mode Class AB differential type Tow-Thomas filter has been synthesized in the log domain. Varying the values of the current sources of the circuit, the natural frequency of the filter as well as the quality factor and DC gain of the circuit can be tuned electronically. The proposed circuit has unity gain and independent of Q quality factor for the band pass filter response. The circuit was simulated in PSpice for both idealized transistor models and CBIC-R type transistors. Various simulations results are given to show the effectiveness of the proposed circuit.

I. INTRODUCTION

The class of Log domain filters is a new member of current mode active continuous time filters and also named as ELIN (Externally Linear Internally Nonlinear) filters, ESS (Exponential State Space) filters and translinear filters in the literature [1-4]. Log domain filters are suitable for low voltage-low power applications. The filters are highly linear, have low distortion, and are electronically tunable [1-3, 5, 6].

Log Domain filters use the natural nonlinear feature of elements directly. While the signal is processed in the circuit nonlinearly, the overall transfer function from input to output remains linear. In the circuit, the input and output variables, dominant variables and control variables are all currents; therefore, the filter is considered to be current mode circuit.

Log domain filters also use the idea of the companding signal processing [3,7]. The input current is first compressed using a logarithmic function while it is forced to drive a BJT transistor since the emitter-base voltage of the device is logarithm of the current. The output circuitry has an expanding block, which means that the output voltage is applied to a BJT's base-emitter to obtain a current of exponential of the voltage. Since the output function is reverse function of the input; the overall transfer function remains linear without using any element to linearize it.

Class AB circuit is a combination of Class A and Class B. This circuit has low noise, low distortion, and high linearity. It also reduces power consumption comparing to Class A [8,9]. Although Class AB is used for amplifications, it was not used for filters until the late 90's [10]. The general theory of Class AB filters in the log domain was developed by Frey and Tola [11,12]. Then, using this theory, various Class AB filters have been designed [13-18].

The type of Tow-Thomas filters is a member of two-integrator–loop circuits which consist of two integrators connected in cascade in an overall feedback loop. In this circuit family, a well known design is called KHN biquad, which consists of one summer block and two integrator blocks. A KHN filter has all the outputs of three fundamental filter responses, namely LP, HP, and BP filters. On the other hand, an alternative circuit derived from the KHN filter is known as Tow-Thomas filter. In this circuit, one integrator block and one summer block are merged. It allows us to use one less block; but, we have no more a HP output [8,19-20].

In this work, Tow-Thomas biquad is synthesized in the log domain. The design is based on the state space synthesis method. The circuit is Class AB and differential type. Its input and output currents are also differential type signals. There are a number of Tow-Thomas or KHN filter designs using op-amp-RC, current-conveyor etc. [8,19-21]; however, this is the first time, to the best knowledge of the authors, that it is designed in the log domain as Class AB. Our BP output response does not depend on the Q factor unlike the classical Tow-Thomas inverting block is eliminated from the circuit. Each block is synthesized in the state space synthesis method. The summing block and one integrator is merged and considered as a single block.

II. SYNTHESIS

The proposed Tow-Thomas circuit is synthesized as Class AB differential type in the log domain. The block diagram of the filter is given in Figure 1.

The input and output variables of the designed circuit are current. The input current is driven into a current splitter [11, 13] to get two input currents, U_L and U_R. These currents which are always positive are applied to two identical nonlinear core filters.

The summing block and one of the integral blocks are merged. Also, the feedback of the first integrator block is added to the first block. Therefore, two main transfer functions are obtained. One is a lossy integrator and the other is pure integrator. The input current and the output of the second integrator are applied to the first integrator. Therefore, we have two-inputs at the first block. In order to satisfy the theory [11,12], variables of each block subscripted by L and R are cross changed if needed. From the block diagram, it is seen that we need two transfer functions. First of all, the first output is defined with two inputs as follows:

$$Y_{BG}(s) = \frac{\omega_o/Q}{s+\omega_o/Q}(KU - Y_{AG}(s)) \tag{1}$$

filter. Using some properties of log domain filters, the Now transferring (1) to time domain, and assigning the output to a state variable,

$$y_{BG} = x_1 \tag{2}$$

we obtain the following differential equation:

$$\dot{x}_1 = \frac{\omega_o}{Q}(-x_1 + Ku - y_{AG}) \tag{3}$$

Following the procedure given by Frey and Tola [12,13] we need the following input and state variables:

$$\begin{aligned} x_1 &= x_{1L} - x_{1R} \\ x_2 &= x_{2L} - x_{2R} \\ u &= u_L - u_R \end{aligned} \tag{4}$$

Applying the following mapping functions to all the input and state variables,

$$x_{ij} = I_S e^{\frac{v_{ij}}{V_T}} \tag{5}$$

$$u_j = I_S e^{\frac{v_{0j}}{V_T}} \tag{6}$$

where i=1,2 and j=L,R, we get the following nodal equation for the L side with Seevinick type dummy input [22]:

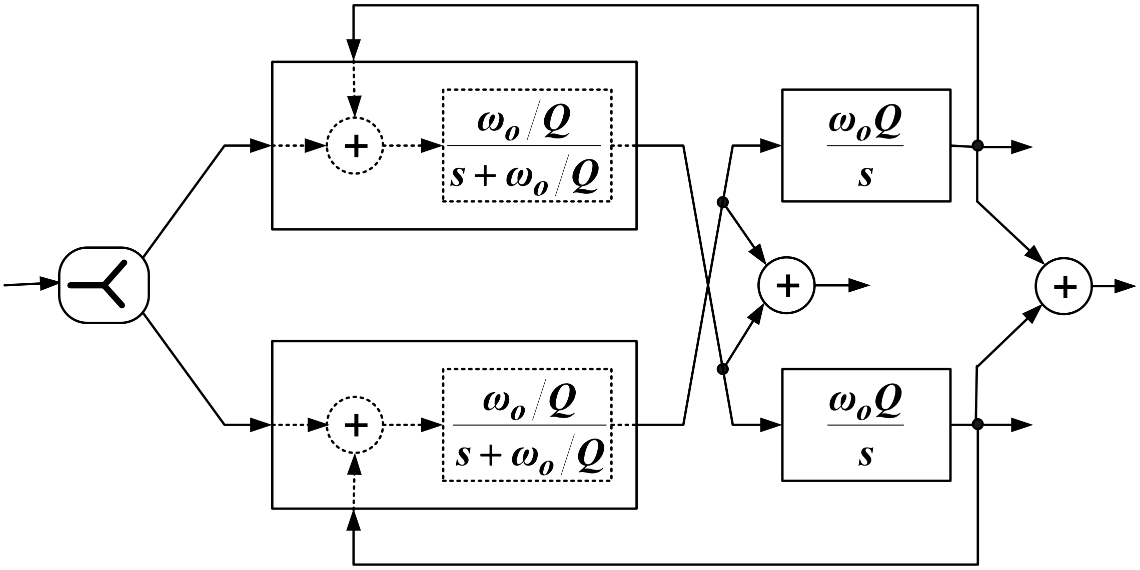

Figure 1: The proposed Tow-Thomas Filter block diagram in differential type log domain.

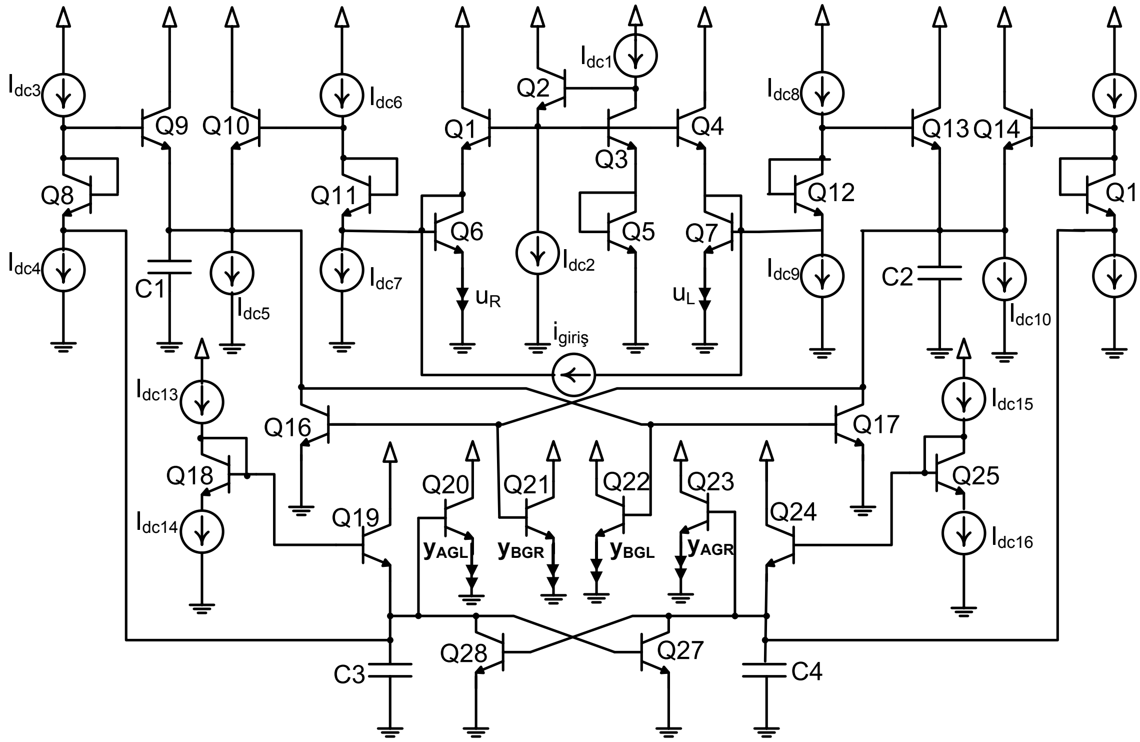

Figure 2: The designed Tow-Thomas Class AB differential circuit in the log domain.

$$C\dot{v}_{BGL} = -\frac{I_f}{Q} + I_s e^{\frac{v_{oL}+V_{f1}-v_{BGL}}{V_T}} + I_s e^{\frac{v_{AGR}+V_{f2}-v_{BGL}}{V_T}} - I_s e^{\frac{v_{BGR}}{V_T}} \tag{7}$$

where

$$I_f = \omega_o C V_T$$
$$I_{f1} = K\frac{I_f}{Q}$$
$$I_{f2} = \frac{I_{f1}}{K} \tag{8}$$
$$I_{f3} = I_{f2} Q^2$$

A similar equation can be written for the R side for the first block diagram. The second output can be written as follows:

$$Y_{AG}(s) = \frac{\omega_o Q}{s} Y_{BG}(s) \tag{9}$$

Choosing another state variable as,

$$y_{AG} = x_2 \tag{10}$$

we end up with the following:

$$\dot{x}_2 = \omega_o Q\, y_{BG} \tag{11}$$

Similarly, we get the following nodal equation for the L side. A similar equation can be written for the R side.

$$C\dot{v}_{AGL} = I_s e^{\frac{v_{BGL}+V_{f3}-v_{AGL}}{V_T}} - I_s e^{\frac{v_{AGR}}{V_T}} \tag{12}$$

Using these equations, a circuit was designed and given in Figure 2.

The circuit is operated with a 1.5V low voltage. Q1-Q7 transistors function as input logging and splitter circuitry [13]. The L side of first integrator contains Q12-Q15 transistors while the R side consists of Q8-Q11 transistors. Q18 and Q19 give the L side of the second integrator whereas Q24 and Q25 give the R side. To satisfy the theorem conditions we need some dummy inputs. These Seevinck type inputs are designed using Q16, Q17, Q27 and Q28 transistors. Finally, Q20-Q23 transistors give the BP and LP output.

III. SIMULATION RESULTS

The synthesized filter is simulated in PSpice for both ideal transistors, i.e. default transistor model with BF=10000, and AT&T CBIC-R type transistors [1]. First simulation is for AC response of the circuit. The filter was set to a 500kHz pole frequency and Q=1 quality factor, and the frequency response of BP and LP filter characteristics are obtained. These responses are given in Figure 3 for both ideal and CBIC-R type transistors. As seen from the figure, there is an acceptable difference between ideal and real transistor models' responses.

Other simulations were performed to tune the pole frequency electronically. Varying the values of the current sources, the filter was tuned from 50kHz to 5MHz. The resulting frequency response for BP output was plotted in Figure 4 using CBIC-R transistors for f_0=50kHz, 500kHz, 5MHz pole frequencies.

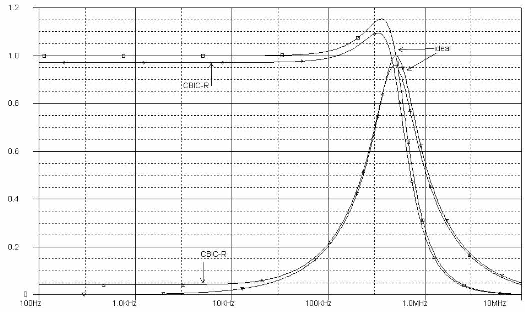

Figure 3: The BP and LP frequency responses for 500 kHz pole frequency.

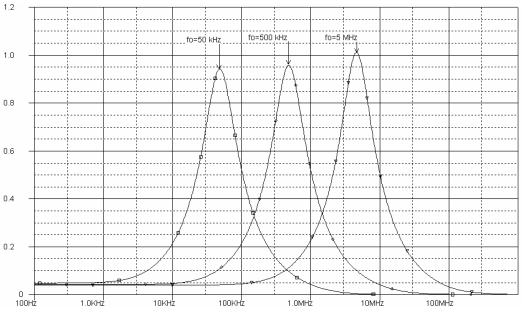

Figure 4: The BP frequency responses for 50 kHz, 500 kHz, and 5MHz pole frequencies.

While the center frequency gain of the band pass filter varies with Q for the original Tow-Thomas filter, our design does not depend on the Q quality factor for the BP output response. Another simulation was performed for the quality factor. By varying the values of current sources, the quality factor of the circuit was tuned electronically. Using the CBIC-R transistors, the resulting frequency response is given in Figure 5 for the BP filter for Q=0.707, 1, 2 and 5. As seen from the figure, for high quality factors, the center frequency gain of the filter was decreased. In this case, the center frequency was set to 500 kHz with If= 10μA DC current.

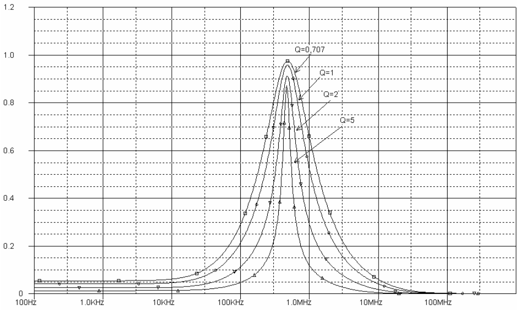

Figure 5: The BP frequency responses for 50 kHz, 500 kHz, and 5MHz pole frequencies.

The proposed circuit has also the ability to change the inband gain by varying some current source's values. To demonstrate this property, the currents were set to 5μA, 10μA, and 15μA and the inband gain was varied 0.5 to 2 linearly. The results for the LP output are given in Table 1.

Table 1: DC gain values for various currents

I_f	DC Gain	
	Ideal	CBIC-R
5μA	0,500	0,485
10μA	1,000	0.971
15μA	2,000	1.942

For the time domain analysis, the circuit was set to 500kHz pole frequency, Q=2 quality factor with I_f=10μA. The transistor currents of the input splitter circuitry were also set to this value. Then, a sinusoidal signal applied to the circuit as input with a 1, 2, 4, 8, and 10 times of this DC value. The output signal's THD was measured for each case. The result for this simulation is given in Table 2.

Table 2: Total harmonic distortion (%)

Input	Output	
	Ideal	CBIC-R
10μA	0.01280	0.04181
20μA	0.01468	0.1199
40μA	0.01640	0.2951
80μA	0.01851	0.6513
100μA	0.02009	0.8139

IV. CONCLUSION

A log domain Tow Thomas filter is presented in this work. The circuit is designed in Class AB and differential type. The block diagram and the state space synthesis methods are used together. The designed circuit has the ability to change the Q quality factor, pole frequency, and DC gain electronically. These features can be obtained only by varying the values of current sources. The circuit was simulated in PSpice for both idealized and real transistors. The results for ideal transistors confirm the theoretical results although some tolerable differences are observed for CBIC-R type transistors.

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