

# Development of Current-Mode First-Order Log-Domain Multifunction Filter

Noravit Kumsing<sup>1\*</sup> and Saweth Hongprasit<sup>2</sup>

<sup>1</sup>Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khon Kaen Campus, Khon Kaen, Thailand, 40000

<sup>2</sup>Department of Computer Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khon Kaen Campus, Khon Kaen, Thailand, 40000

bankjusgee@gmail.com\* and saweth12@gmail.com

**Abstract.** *The current-mode first-order multifunction filter based on log-domain integrator is proposed in this paper. The filter consists of sixteen bipolar junction transistor (BJT) and one capacitor. The main circuit operation is divided into 2 parts: a log-domain lossy integrator and a current mirror circuit. The proposed filter has one input and three outputs: low-pass, high-pass, and all-pass responses. All the output signals are produced from the summing and subtracting of the currents in each branch of the output stage. The PSpice simulation results were used to verify the principle and theory.*

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current-mode, first-order, log-domain, integrator, filter

## 1. Introduction

Log-domain filters are used for synthesize the filters circuits by creating a linear system from nonlinear devices. This circuit has advantages in low power supply voltage, large dynamic range, and high frequency response [1]. Log-domain technique is not actually linear because its inputs and outputs are relatively linear but with, in fact, internally non-linear [2]. The log-domain filter has a logarithm function to compress the input signal and exponential function to expand the signals at the output stage. This method can be created by using the non-linear relationship between the voltage and current of bipolar transistors when they are being biased to work in the active region.

Adams introduced the concept of filtering in the log-domain in 1979[3]. He presented the first log-domain filter by using logarithm function and exponential function technique in conjunction with a combination of forward biased diodes and a capacitor to be able to a distortionless first-order low-pass filter [2]. A working behavior of log-domain filter is the same as companding circuit introduced by Tsividis in 1990 [4]. In the

same year, Seevinck proposed the companding current-mode integrator [5], was designed based on class AB translinear loops principle to extend the dynamic range and to reduce noise. In 1993, log-domain filters were synthesized by the state-space technique which was presented by Frey [6,7]. Such filters consist of a simple building block and a bipolar current mirror. The log-domain filters are based on the instantaneous companding integrators [8-10] which provided high frequency response, electronically tuned, low supply voltage, low power operation, and can be extended the dynamic range. There were several related works published in [11-15].

A multifunction filter had been discovered long time ago [16]. In the recent years, there were many multifunction filters based on several active devices: a single CCDDCCTA has one grounded capacitor that can only function to realize voltage-mode and current-mode first-order multifunction filter [17], a single M-CCCCTA uses only one grounded resistors and one grounded capacitor to obtain voltage-mode first-order multifunction filter by modification of CCCCTA [18], three OTRA consists of six resistors and three capacitors to obtain the first-order multifunction filter [19]. However, from the examples mentioned above, there are many passive and active devices thereby making complicated structures and high power consumption.

Therefore, the proposed circuit presents the current-mode first-order multifunction filter based on log-domain integrator implemented from sixteen bipolar junction transistors (BJT) and one capacitor. The circuit has single input but provides three output frequency responses: low-pass(LP), high-pass(HP), and all-pass(AP) response. The cutoff frequency and phase response can be electronically tuned by adjusting the bias current  $I_{bias}$  in the cutoff frequency equation. Then, the simulation with PSpice program was used to verify the principle and theoretical analysis.

## 2. Proposed multifunction filter

The main core of the proposed circuit in this paper is a first-order low-pass filter. It was designed base on the log-domain integrator principle, which consists of four NPN bipolar junction transistors and one capacitor as show in Fig. 1

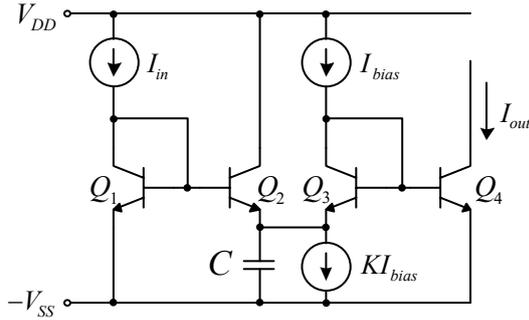


Fig. 1: Log-domain first-order LP filter

The circuit in Fig. 1 is defined to all the parameters of the transistor are matched. Consider the base-emitter voltage relations of the transistor by using Kirchoff's voltage law (KVL) can be written by:

$$V_{BE1} + V_{BE3} = V_{BE2} + V_{BE4} \quad (1)$$

The collector current of bipolar transistor is:

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \quad (2)$$

and

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) \quad (3)$$

Where  $V_T$  is the thermal voltage, it is equal  $25mV$  at room temperature and  $I_S$  is the saturation current. So, Eq. (1) can be rewritten as follows:

$$V_T \ln\left(\left(\frac{I_{C1}}{I_S}\right)\left(\frac{I_{C3}}{I_S}\right)\right) = V_T \ln\left(\left(\frac{I_{C2}}{I_S}\right)\left(\frac{I_{C4}}{I_S}\right)\right) \quad (4)$$

Rearranging Eq. (4) can be given by:

$$I_{C1}I_{C3} = I_{C2}I_{C4} \quad (5)$$

From Fig. 1, we can determine the collector current with defining the  $I_{C1} = I_{in}$ ,  $I_{C3} = I_{bias}$  and  $I_{C4} = I_{out}$  Eq. (5) becomes:

$$I_{in}I_{bias} = I_{C2}I_{out} \quad (6)$$

Collector current of  $Q_2$  is:

$$I_{C2} = sCV\dot{C} + KI_{bias} - I_{bias} \quad (7)$$

The results of  $\dot{V}C$  from differentiating the  $VC = V_{be1} - V_{be2}$  can be obtained by:

$$I_{in}I_{bias} = (sCV_T + KI_{bias} - I_{bias})I_{out} \quad (8)$$

Eq. (8) can be rearranged and obtained the transfer function of the circuit as:

$$\frac{I_{out}}{I_{in}} = \frac{I_{bias}}{sCV_T + KI_{bias} - I_{bias}} \quad (9)$$

Where  $K$  is constant values, defined by  $K = 2$ , the transfer function of the first-order low-pass filter can be written as:

$$\frac{I_{out}}{I_{in}} = \frac{I_{bias}/CV_T}{s + (I_{bias}/CV_T)} \quad (10)$$

or

$$H(s) = \frac{I_{out}}{I_{in}} = \frac{\omega_0}{s + \omega_0} \quad (11)$$

When  $\omega_0 = I_{bias}/CV_T$ ,  $\omega_0$  is the cut-off frequency, the  $\omega_0$  can be adjusted by bias current  $I_{bias}$ .

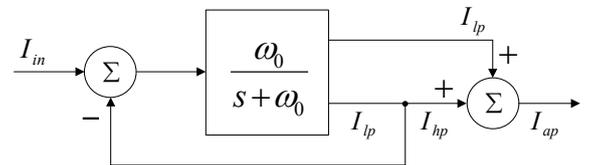


Fig. 2: Block diagram of log-domain first-order multifunction filter

The design concept of the proposed circuit is shown with block diagram, which can be obtained by combining the low-pass block is in formed of lossy integrator with two arithmetic blocks as shown in Fig.2. The proposed circuit is able to provide the multiple output signals from a single

input. The current transfer functions of proposed first-order log-domain multifunction filters to be derived from the current in each branches of circuit in Fig.3 are given as Eqs. (12)-(14).

$$\frac{I_{lp}}{I_{in}} = \frac{I_{bias}/CV_T}{s + (I_{bias}/CV_T)} \quad (12)$$

$$\frac{I_{hp}}{I_{in}} = -\frac{s}{s + (I_{bias}/CV_T)} \quad (13)$$

$$\frac{I_{ap}}{I_{in}} = \frac{-s + (I_{bias}/CV_T)}{s + (I_{bias}/CV_T)} \quad (14)$$

The complete schematic of the proposed circuit as shown in Fig.3 can be derived from the current transfer

functions of low-pass, high-pass and all-pass filters as following:

$$H(s) = \frac{I_{lowpass}(s)}{I_{in}(s)} = \frac{\omega_0}{s + \omega_0} \quad (15)$$

$$H(s) = \frac{I_{highpass}(s)}{I_{in}(s)} = -\frac{s}{s + \omega_0} \quad (16)$$

$$H(s) = \frac{I_{allpass}(s)}{I_{in}(s)} = \frac{-s + \omega_0}{s + \omega_0} \quad (17)$$

The cutoff frequency of the proposed filter can be electronically tuned by adjusting the bias current  $I_{bias}$ .

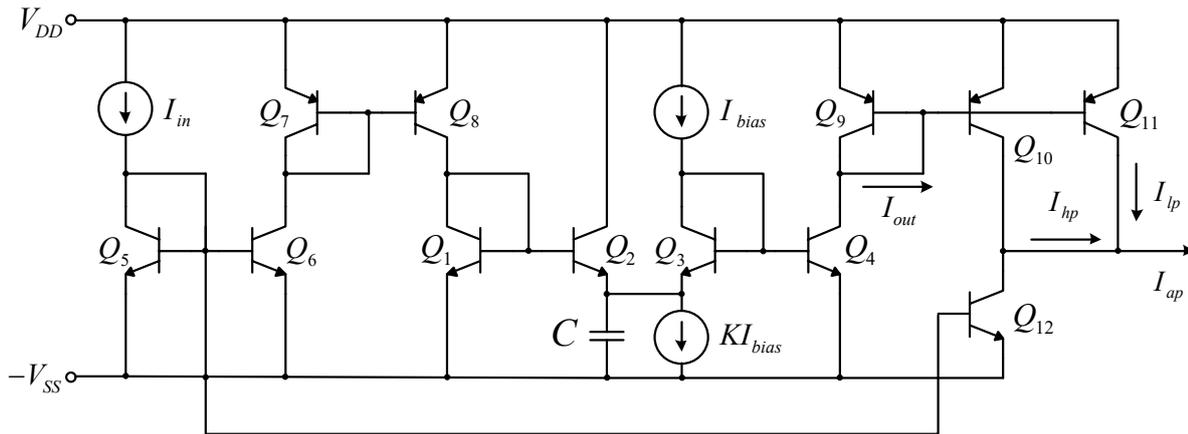


Fig. 3: The proposed current-mode first-order multifunction filter

### 3. Simulation Results

To confirm the theory and principles of the proposed filter circuit shown in Fig. 3, the PSpice program with parameters of ultrahigh frequency transistor arrays (HFA3046-NPN), (HFA3096-PNP) was used. The supply voltages  $V_{DD} = -V_{SS} = 2V$ ,  $I_{bias} = 60\mu A$ ,  $I_{in} = 10mA$  and capacitor  $C = 800pF$ . The gain response for the LP, HP and AP are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. The gain and phase response of AP as shown in Fig. 7 and the cutoff frequencies are varied by adjusting the bias current with different values as shown in Fig.8.

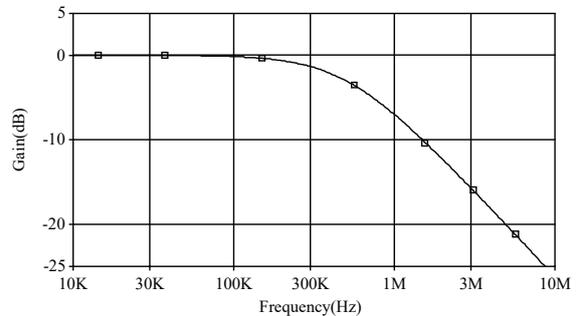


Fig. 4: Gain response of LP

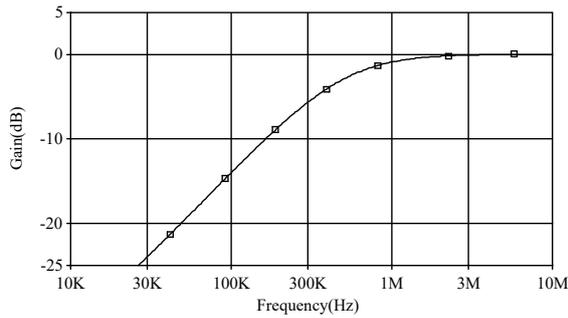


Fig. 5: Gain response of HP

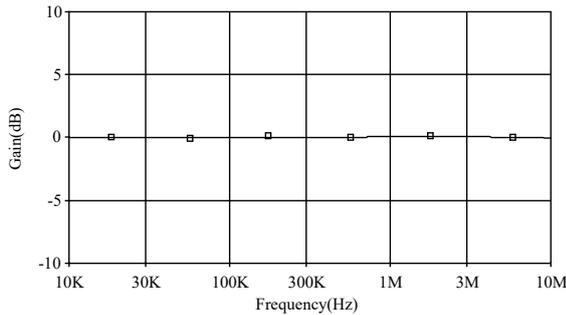


Fig. 6: Gain response of AP

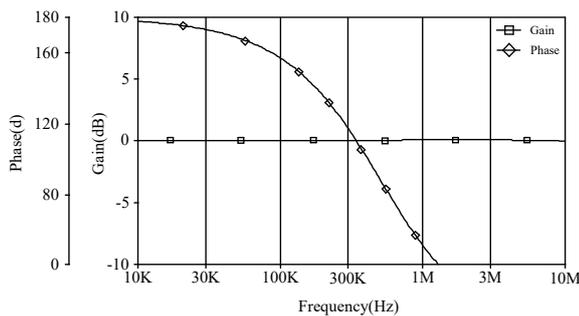


Fig. 7 Gain and Phase response of AP

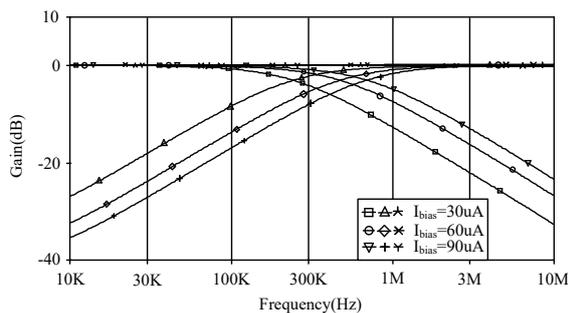


Fig. 8: Cutoff frequency by adjusting the bias current  $I_{bias}$

### 4. Conclusion

This paper presented the current-mode first-order multifunction filter based on log-domain integrator using only BJT transistors and capacitor. The filter can be provided the three output frequency responses: low-pass, high-pass and all-pass, which operated at  $\pm 2V$  DC power supply. Wide-range tunable frequency response can be electronically tuned by

changing the value  $I_{bias}$ . The PSpice simulation results are used to confirm the circuit performance of the proposed, found that the results are agreeable with theory and principle.

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department of computer engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khon Kaen campus, Thailand. His research interests include CMOS circuit design, analog signal processing, current mode circuits, active filters and oscillators.

## Biographies



**Noravit Kumsing** received the B.Eng. degree in Computer Engineering from Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus, Thailand in 2017. He is currently pursuing Master's degree in Electrical Engineering at the same university. His research interests include CMOS circuit design, analog signal processing and internet of things (IoT).



**Saweth Hongprasit** received the B.Ind.Tech. in electrical engineering from Mahanakorn University of Technology (MUT), M.Tech.Ed. in electrical technology from King Mongkut's Institute of Technology North Bangkok (KMITNB) and Ph.D. in Electrical and Computer Engineering from Mahasarakham University (MSU), Thailand in 1995, 2007 and 2012, respectively. He has been a lecturer at