International Journal of Scientific and Technical Advancements

ISSN: 2454-1532

Comparison of Higher Order Log Domain Low Pass Filters

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Abstract—This paper uses sub-threshold MOSFET for designing various low voltage log-domain low pass filters. Earlier BJTs were used for designing Log-domain filters which offer higher transconductance and high frequency response but do not favour down scaling and high integration. Therefore, CMOS version of log-domain filters is desired. In this paper, we exhibits first, second and fourth order log domain low pass filter which shows linear characteristics with low currents, hence useful for low power and low frequency applications. The log-in and log-out circuits have been used along with integrators to implement first and second order low pass filters. The first order log-domain low pass filter exhibits bandwidth of 631 MHz while second order log domain low pass filter has bandwidth of 15.9 MHz with the supply voltage of 1 V and capacitor of 2.0 pF value. The cascade of second order sections has been used to realize a fourth order low pass filter which exhibits a pass band gain of 0 dB and -3 dB cut-off frequency of 1.26 MHz. The behavior of these circuits has been verified through PSpice simulations using level 7 parameters in 0.13 μm technology with supply voltage of 1V.

Keywords— Analog filters, subthreshold MOSFET, log-domain low pass filters.

I. INTRODUCTION

Analog integrated circuit(IC) design is becoming increasingly becoming increasingly important in view of its applications in the diverse field of electronics. As the frequency of communication system increases and the dimensions of transistor are reduced, more and more stringent performance requirements are placed on analog circuits. Due to the ongoing trends of low voltage and low power operation, the area of analog integrated filters is facing serious challenges It is well known that maximum dynamic range achievable using conventional filter implementation techniques such as op-amp MOSFET – C,(MOS-C) transconductance–c (gm-c) and switched capacitor, is becoming severely restricted by the supply voltage. Among these, gm-c, MOS-C, filters are the two most popular integrated, continuous –time filters, gm-c filters offer reasonably high bandwidth, but they suffer from there poor linearity. MOS-C filters have less distortion, but the band width is limited due to op-amps finite -3dB bandwidth. [1-3]. In the view of above facts, novel techniques for the design of first, second and fourth order analog filters are introduced in this work. To achieve these goals, a companding technique known as Log Domain filtering has been used which uses the log –exponential nature of bipolar transistor or MOSFET operating in weak inversion region to obtain dynamic Trans-linear circuit. A log-domain filter is new type of continuous time filter suitable for low voltage and low power applications. These circuits basically implement an input-output linear system using non-linear components and work on translinear principle. Since BJT is an inherent translinear element, therefore log-domain filters were originally implemented in bipolar technology. Though BJTs offer higher transconductance and high frequency response but are not much subjected to down scaling, therefore, MOS versions of log-domain filters is necessary for integration [5, 7, and 8]. All BJT log-domain filters can be implemented in CMOS by replacing BJTs with MOSFETS biased in sub-threshold region. The sub-threshold MOSFET acts as translinear element exhibiting non-linear characteristics with low currents, hence useful for low power and low frequency applications. The concept of log domain filtering was first introduced by Adam's [2] in the 1970's but it require nearly ten years in establishing the fundamental principles of log domain circuit design .It was only recently that the idea was expanded by Frey into a general filter design approach[3]. In log domain filtering technique, transistors need not be linearised as compression is followed by expansion. The additional advantage of Log Domain filter is there greater bandwidth which is due to low intermediate nodes. Log domain filters have input and output as current signals, which classify them as "current-mode" circuits. In this paper we have presented first, second and fourth order log domain low pass filters, and their comparison.

II. PRINCIPLE OF LOG DOMAIN FILTER

The principle of operation of log domain circuits is based on instantaneous companding where the signals in current form with large dynamic range are compressed logarithmically during transformation into voltages and later expanded exponentially when converted back into current form.

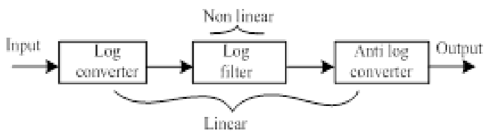

Fig. 1. Basic log domain filter.

Therefore, log domain technique is very well suited to the implementation of continuous-time analog signal processing circuits that have to operate at very low supply

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voltages. The schematic of the log domain filter is shown in Fig. 1 which comprises of three non-linear building blocks namely the compressor, the logarithmic filter and the expander.

III. First Order Log Domain Low Pass Filter

A first order low pass filter including log-in and log-out circuits is shown in Fig. 2 [4]. The log-in and log-out circuits are used to make circuit linear with respect to both current input and output variable

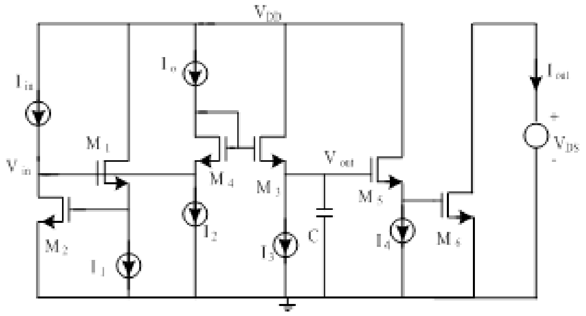

Fig. 2. First order log domain low pass filter

The log-in circuit is interfaced at the input of the filter to perform current to voltage conversion and compression while log-out circuit is interfaced at the output of the filter to perform a voltage to current expansion. The first order log domain low pass filter has been simulated for level 7 PSpice parameters for 0.13 µm technology with supply voltage 1 V and I_{in} current is 10µA . The aspect ratio of M_1 has been taken as 117 µm /0.13 µm. The frequency response of first order log domain low pass filter is shown in Fig. 3. The simulation results shows that pass band gain is 0 dB and -3 dB cut-off frequency is 631 MHz.

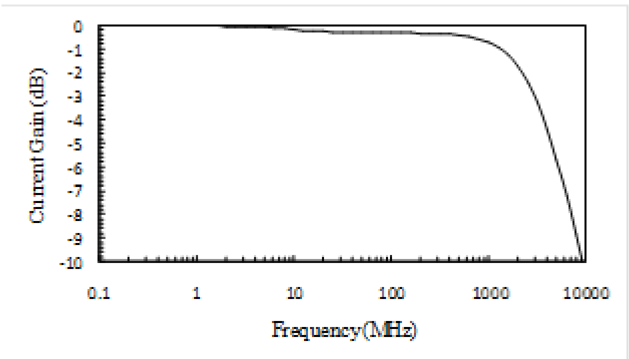

Fig. 3 Magnitude response of first order log domain low pass filter.

IV. Second Order Log Domain Low Pass Filter

The circuit of second order log domain low pass filter as shown in Fig. 4 comprises of six MOSFETs and two capacitors [6]. In this circuit M_5 and M_6 will not draw any extra power from the supply since they share the same dc current with M_3 circuit. The grounded capacitors in the circuit are desired for integration.

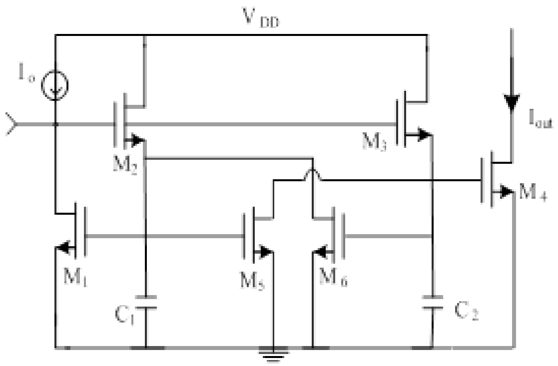

Fig. 4. Second order log domain low pass filter.

To ascertain the workability of the circuit shown in Fig. 4, PSpice simulation was used by selecting W/L of M_1, M_5 & M_6 as 0.104µm/0.13 µm and W/L of M_2, M_3, M_4 is .52 µm /.13 µm respectively with the supply voltage of 1 V. The capacitor chosen is of 2.0 pF value. The frequency response of this circuit is shown in Fig.5, which exhibits -3 dB cut-off frequency of 15.9 MHz and pass band gain of 0 dB. We have also observed that as order of the filter increases, bandwidth decreases and response falls faster in stop band.

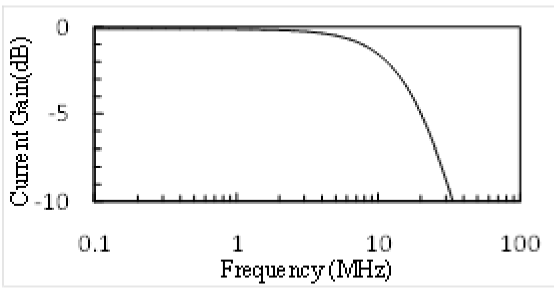

Fig. 5. Magnitude response of second order log domain low pass filter.

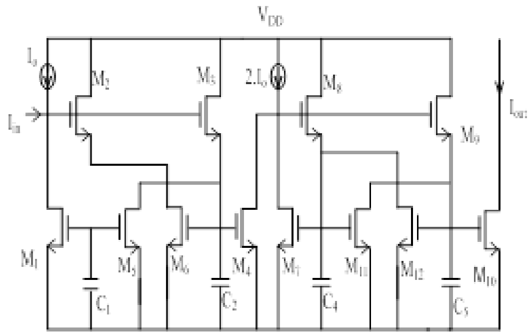

Fig. 6. Fourth order log domain low pass filter.

V. Fourth Order Log Domain Low Pass Filter

The standard approach of building higher order filters is to cascade the basic filter sections of first and second order [6]. For odd order filters, first and second order sections are cascaded and for even order filters, simply second order sections are cascaded. The cascading results in lowering of resultant cut off frequency than that of individual filter sections. In order to demonstrate the cascading principle for

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higher order filters, we have considered the case of fourth order log domain low pass filter. The fourth order log domain low pass filter has been realized by cascading two sections of second order log domain low pass filter of Fig.4 and the resultant circuit is shown in Fig. 6.

The general expression for overall high -3dB frequency in a multistage amplifier is given by

$$f_2^* = f_2 (2^{\frac{1}{n}} - 1)^{0.5} \quad (1)$$

Similarly, the general expression for overall lower -3dB frequency in a multistage amplifier is given by

$$f_1^* = f_1 (2^{\frac{1}{n}} - 1)^{-0.5} \quad (2)$$

where f_1 & f_2 are lower and upper -3dB frequencies of individual amplifier stage. In the case of low pass filters we have $f_1 = 0$. Therefore, from Eqns. (1) & (2), we find that f_2^* is lower than f_2 and f_1^* is higher than f_1. Hence, the overall bandwidth shrinks which consequently results in increase of quality factor of the filter.

The behavior of circuit in Fig. 6 has been verified through PSpice simulations using level 7 parameters in 0.13 µm technology with supply voltage of 1 V. The frequency response of fourth order log domain low pass filter is shown in Fig. 7.

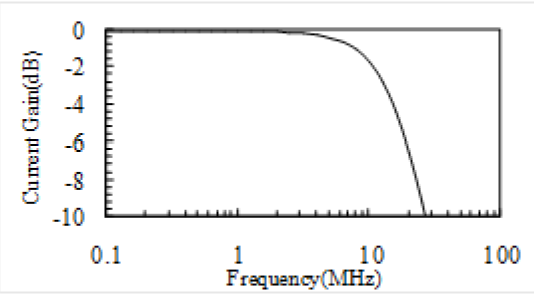

Fig. 7. Magnitude response of fourth order log domain low pass filter.

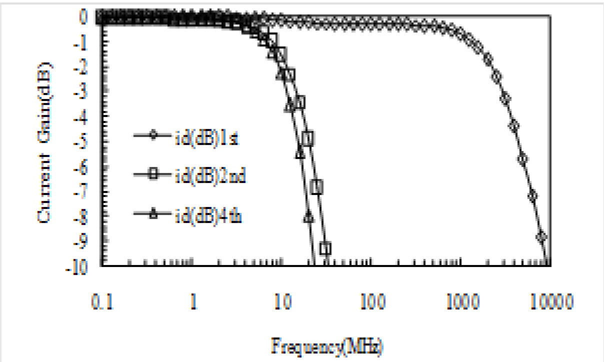

Fig. 8. Magnitude response of different order log domain low pass filters

The simulated response exhibits a pass band gain of 0 dB and -3 dB cut-off frequency of 11.26 MHz. Therefore, we conclude that as we increase the order of filter we lose bandwidth and get better frequency response in stop band. The comparative frequency response of first, second and fourth order log domain low pass filters is shown in Fig. 8. We have observed that as filter order increases bandwidth decreases but response falls steeply in stop band as shown in Fig. 8 and Table I.

Table I. Effect of order on filter performance

Filter order	Pass band gain	-3dB frequency
First order	0 dB	631 MHz
Second order	0 dB	15.9 MHz
Fourth order	0dB	11.26MHz

VI. Conclusion

In this paper, we have presented CMOS log-domain low pass filters of first and second order. A cascade of second order filter sections has been used to realize a fourth order filter. These circuits utilize grounded capacitors which are desired for integration point of view since they occupy less chip area. The behavior of filter circuits has been verified through PSpice simulations carried out using level 7 parameters in 0.13 µm CMOS technology with a supply voltage of 1 V. The simulation results have been found to justify mathematical formulations.

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