A Fully-Balanced Current-Tunable Gm-C Low Pass Filter

Samran Lertkonsarn

Department of Electrical Engineering Faculty of Engineering, Pitchayabundit College, 171/2 Moo.2
Nong Bua, Muang District Nong Bua Lamphu, Thailand

samranlertkonsarn@gmail.com

Abstract. *This paper proposes a circuit of a fully balanced, current-tunable Gm-C low pass filter (LPF). The proposed circuit is relatively simple and symmetrical with different signals. The filter consists of six bipolar junction transistor (BJT) and one capacitor. The tuning range of the filter's cutoff frequency is from 4.2793 Hz to 2.0279 MHz. The filter operates from a supply of 1.5 V. Simulation results using PSpice program for the proposed reconfigurable LPF are presented.*

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Low Pass Filter (LPF), Fully-balance, Gm-C

1. Introduction

In the rapid development of the wireless communication field, the transceiver system with high performance is a hot research area in recent years [1]. The filter is one of the most important part in this system, Low Pass Filter (LPF) is widely used to remove undesired harmonics or spurious of the mixing products in the nonlinear portion of RF front-end and baseband circuits. For LPF, wide-and good-stopband rejection is important to achieve good signal-over-noise ratio and to reduce the bit error rate for the high-data-rate wired or wireless communication systems [2]-[12], A Gm-C filter is a kind of the continuous-time filter which needs the operational transconductance amplifier to be a basic building block. The cutoff frequency of a Gm-C filter is directly proportional to the gain of trans-conductance and inversely proportional to the capacitance. The Gm-C filters have many applications in communication systems as they can reach the highest frequency and a body of literature has been published [13]. Switched-capacitor filter has been successfully applied to many voice band applications. It has good accuracy of time constants and good temperature characteristics; whereas the problem of clock feedthrough is difficult to be solved and it also needs continuous-time filters as anti-aliasing filters [12]. Another alternative is to use Gm-C filters which do not have the aliasing problem of sampled-data systems. Due to the dependence of the cutoff frequency of the filter on the absolute values of monolithic components such as capacitors and transistor transconductances, which are both process and temperature dependent, feedback and cancellation techniques are required to control the cutoff frequency of this type of filters. And it also needs a small transconductance in order to avoid using large area capacitors at low frequency [13].

In this paper, a relatively simple circuit technique to realise an integrable fully-balanced current-tunable Gm-C low pass filter presented. The cutoff frequency filter is linearly current-tunable using a tunable r_e network where r_e is the small-signal dynamic resistance of a forward biased base-emitter junction of a bipolar transistor.

2. Circuit Descriptions

Fig. 1 shows the proposed circuit a fully-balanced current-tunable Gm-C low pass filter consisting of six matched npn transistor T1 to T6, capacitor C and one identical current sinks of value I_f. A small-signal input voltage is V_{AB} between the bases of T1 and T4 (or nodes A and B). A small-signal output voltage is V_{DE} between the emitters of T5 and T6 (or nodes D and E). The corner frequency ω_0 of the low pass typically defined at the point where the magnitude and the phase shift of its transfer function V_O/V_{in} become -3 dB and -45 degree, respectively, is tunable using a current-tunable four loading diode-connected transistors R = $4r_e$, formed by T1, T2, T3 and T4.

A current sinks may be implemented through the conventional Wilson current mirrors and convert a frequency setting current I to bias T1, T2, T3, T4, T5 and T6. It can be seen from Fig. 1 that the architecture of the circuit is symmetrical and hence the name "fully-balanced" low pass.

3. Ideal Analysis

Referring to Fig. 1, Firstly, Feed A small-signal input voltage of V_{AB} between the emitters of T3 and T4 (or nodes A and B), Enables a small-signal current I1 passing through the emitters of T1, T2, T3, T4 and C can be expressed in equation (1)

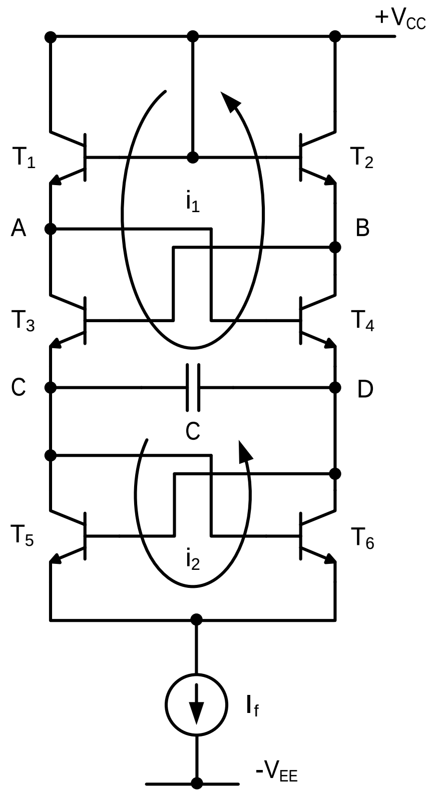

Fig. 1: A Fully-Balanced Current-Tunable Gm-C Low Pass Filter

$$I1 = \left(\frac{V_{in}sC}{4r_e sC + 1} \right) \quad (1)$$

And a small-signal current I2 as emitter resistance T5, T6 (or nodes C and D), of the from

$$I2 = \left(\frac{V_o}{2re} - \frac{I1}{sC} \right) \quad (2)$$

Substituting (1) with (2) yields

$$\frac{V_o}{V_{in}} = \frac{2re}{4resC + 1} \quad (3)$$

I can be seen from (3) $\tau = 4reC$, of the from

$$\frac{V_o}{V_{in}} = \frac{2re}{\tau s + 1} \quad (4)$$

The corner frequency of (4) is $\omega_0 = 1/\tau = 1/4reC$. The corner frequency ω_0 is current tunable by I_f of the form

$$\omega_0 = \frac{I_f}{4CV_T} \quad (5)$$

4. Sensitivities

Generally, a sensitivity of y to a variation of x is given by $S_x^y = [\partial y / \partial x][x / y]$ where y is a parameter of interest and x is a parameter of variation [15, 16]. Since, the thermal voltage V_T, capacitance C and current sink I_f also represent effect of temperature on the corner frequency ω_0 , as shown in equation (5). Therefore, Table 1 shows the sensitivity S_x^y ; where (C, ω_0) , (V_T, ω_0) or (I_f, ω_0) . Consequently, It can be seen from Table 1 the sensitivities of ω_0 are relatively constant between -1 to 1. Such sensitivities are unlike existing approaches [16]-[18]

$S_C^{\omega_0}$	$S_{I_f}^{\omega_0}$	$S_{V_T}^{\omega_0}$
-1.0	1.0	-1.0

Table 1: Sensitivity S_x^y ; where (C, ω_0) , (V_T, ω_0) or (I_f, ω_0)

5. Simulation Results

The performance of the circuit shown in Fig.1 has been simulated using a Spice [19]. The npn transistors are modeled by 2N2222A, whose transition frequency f_T is at 300 MHz. Fig.2 illustrates magnitude (dB) and phase shift (degrees) of V_o/V_{in} versus frequency (Hz) obtained from the simulation using, for example, capacitor C = 10 nF and I_f = 0.001 A, 0.003 A and 0.009 A.

It can be seen from Fig.2 that, the corresponding frequency ω_o, where the magnitude of V_o/V_{in} is become -3 dB for individual values of I_f are at 2.071 kHz, 5.682 kHz and 15.786 kHz, respectively, and the corresponding phase shifts for individual values of I_f are all approximately -45 degree. Fig.3 depicts the simulation results of both the corner frequencies (Hz) of V_o/V_{in}, versus the bias current I_f(A), using capacitor C = 10 nF. For the comparative purposes, the ideal (expected) results are also included. It can be seen from Fig.3 that both the expected and the simulated results are consistent, and the frequency f_o is linearly current-tunable over a "wide-frequency" sweep range of approximately 3rd order of magnitude.

Fig. 4 shows the simulation results of both the corner frequencies (Hz) and the corresponding phase shift (degrees) of V_o/V_{in} is become -3 dB, versus the capacitance C, using a fixed bias current I_f of value 1 mA. For purposes of comparison, the ideal (expected) results are also included. It can also be seen form Fig. 4 that both expected and the simulated results are linear and consistent and, by using a minimum frequency setting capacitance of 0.01 nF, the upper frequency limit can be expected to be 2.0273 MHz.

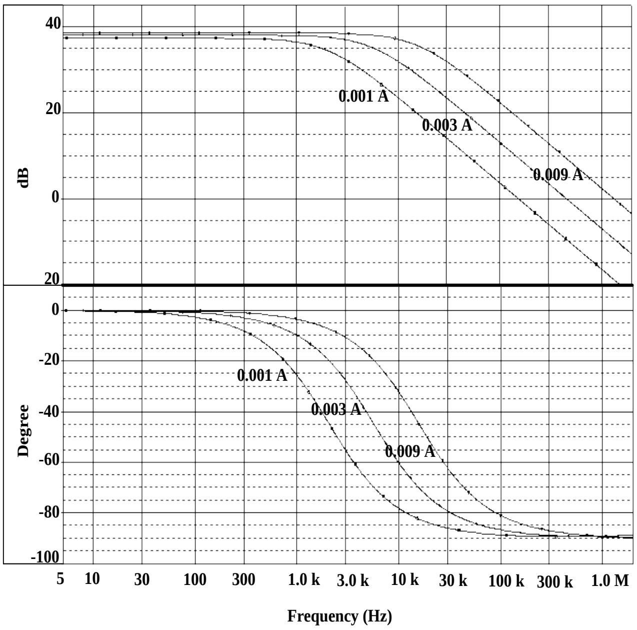

Fig. 2: Magnitude (db) and Phase shift (degree) of V_o/V_{in} versus frequency (Hz) using the capacitance C = 10 nF and current I_f = 0.001 A, 0.003 A and 0.009 A

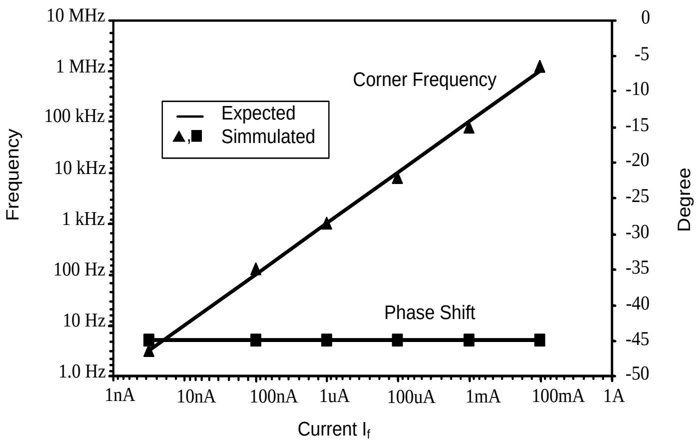

Fig. 3: Corner frequencies (Hz) and the corresponding phase shift at -45 degree of V_o/V_{in} versus the bias current I_f (A), using a fixed capacitance C of value 0.01 nF.

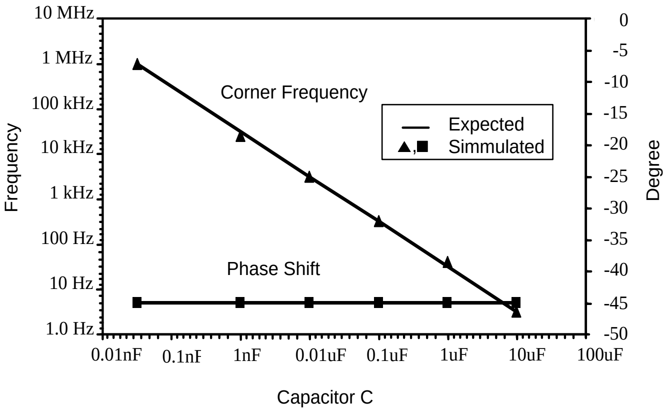

Fig. 4: Corner frequency (Hz) and the corresponding phase shift at -45 degrees of V_o/V_{in} versus the capacitance C (F), using a fixed bias current I_f of value 1mA.

6. Conclusions

A Fully-Balanced Current-Tunable Gm-C Low Pass Filter has been proposed. The architecture of the circuit is symmetrical with different signals. Both the simulated and ideal results are consistent. It is a simple procedure that has been presented for approximating the transfer characteristic of linearized bipolar emitter-coupled pairs. Sensitivities of either the ω have been constant between –1 to 1 independent of variables. The corner frequency is linearly current-tunable over a wide-frequency sweeping range of three orders of magnitude. The maximum useful corner frequency is around 2.0279 MHz.

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Biography

Samran Lertkonsarn was born in Thailand. He received his M.Eng.(Electrical and Computer Engineering) from Mahasarakham University, Thailand, in 2011. His research interests include the IC design.