วงจรกรองสัญญาณผ่านทั้งหมดชนิดมีมุมองศานำ วงจรมีความสมมาตรและปรับค่าความถี่ได้กว้าง โดยการปรับค่ากระแส

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บทคัดย่อ

บทความนี้นำเสนอวงจรกรองสัญญาณผ่านทั้งหมดชนิดมีมุมองศานำ (Phase-Lead All-Pass Filter) วงจรถูกนำไปสร้างเป็นวงจรรวมได้ สถาปัตยกรรมของวงจรไม่สลับซับซ้อน และสมมาตร (Symmetry) ด้วยสัญญาณความแตกต่าง (Differential signals) ค่าของความถี่ f_0 ณ จุดที่ขนาด (Magnitude) และมุมองศา (Phase shift) ของฟังก์ชันถ่ายโอน (Transfer function) มีค่าเป็น 0 เดซิเบล และ +90 องศา ตามลำดับ ถูกปรับค่าได้กว้างแบบเชิงเส้นตลอดย่านความถี่ถึง 1000 เท่า โดยการปรับค่าของกระแสตรง ความถี่ f_0 ใช้งานประมาณ 220 เมกะเฮิรตซ์

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A Fully Balanced Wide-Frequency Current-Tunable Phase-Lead All-Pass Filter

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Abstract

A new integrable fully-balanced wide-frequency current-tunable phase-lead all-pass filter is presented. The architecture of the circuit is relatively simple and symmetry with differential signals. The frequency f_0 where the magnitude and phase shift of the transfer function are approximately 0 dB and +90 degrees, respectively, is linearly tunable, through a bias current, over a wide-frequency sweep range of approximately three orders of magnitude. The maximum useful frequency f_0 is in excess of 220 MHz.

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1. Introduction

All-pass filters are utilised in many applications such as in sinusoidal quadrature oscillators in an integrated receiver. It is usually desirable that the architecture of such devices is fully balanced with differential signals so as to enable, for example, accurate quadrature outputs with maximum symmetry over a wide tunable-frequency sweep range. There are other significant, well understood advantages in employing a fully balanced realisation [1]. However several techniques of all-pass filters have not been fully balanced [2]-[4]. Recently, a fully balanced wide-frequency current-tunable phase-lag all-pass filter has been reported with the maximum useful frequency of approximately 112 MHz [5]-[7].

In this paper, an integrable fully balanced wide-frequency current-tunable phase-lead all-pass filter is presented. The architecture of the circuit is relatively simple and symmetry with differential signals. The frequency ω_0 where the magnitude and phase shift of the transfer function are approximately 0 dB and +90 degrees, respectively, 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. The maximum useful frequency is approximately 220 MHz.

2. Circuit Descriptions

Fig. 1 shows the basic circuit configuration of the fully balanced current-tunable phase-lead all-pass filter consisting of ten matched npn transistors Q1 to Q10, a capacitor C and current sinks I_1 and I_f. The differential, small-signal, input voltage V_{in} is applied to the bases of two differential pairs (Q1-Q2) and (Q3-Q4), between nodes A and B. The resulting differential, small-signal, output voltage V_o is taken across the emitters of Q9 and Q10, between nodes G and F.

The current sinks I_1 and I_f may be implemented through the conventional Wilson current mirrors. Current $I_1/2$ biases the (Q3, Q9) and the (Q4, Q10) branches, whilst a frequency setting current I_f biases the (Q1, Q8, Q7) and the (Q2, Q5 and Q6) branches. It can be seen from Fig. 1 that the architecture of the circuit is symmetry and fully-balanced. The circuit is also relatively simple and is "integrable" as all active devices can be fabricated on-chip.

3. Ideal Analysis

Referring to Fig. 1, assuming that the bases of Q9 and Q10 at nodes D′ and E′ are temporarily disconnected with nodes D and E, and as a result the bases of Q9 and Q10 at D′ and E′ are then temporarily connected together with an appropriate bias voltage say V_{bias}. Such a temporary case is illustrated in Fig. 2 and 3, where the resulting differential, small-signal, output voltage across nodes D and E be V_{o1}, as shown in Fig. 2, and that across nodes F and G be V_{o2}, respectively. The differential, small-signal, input voltage V_{in} results in a differential output current i_{d1} as shown in Fig. 2 and therefore

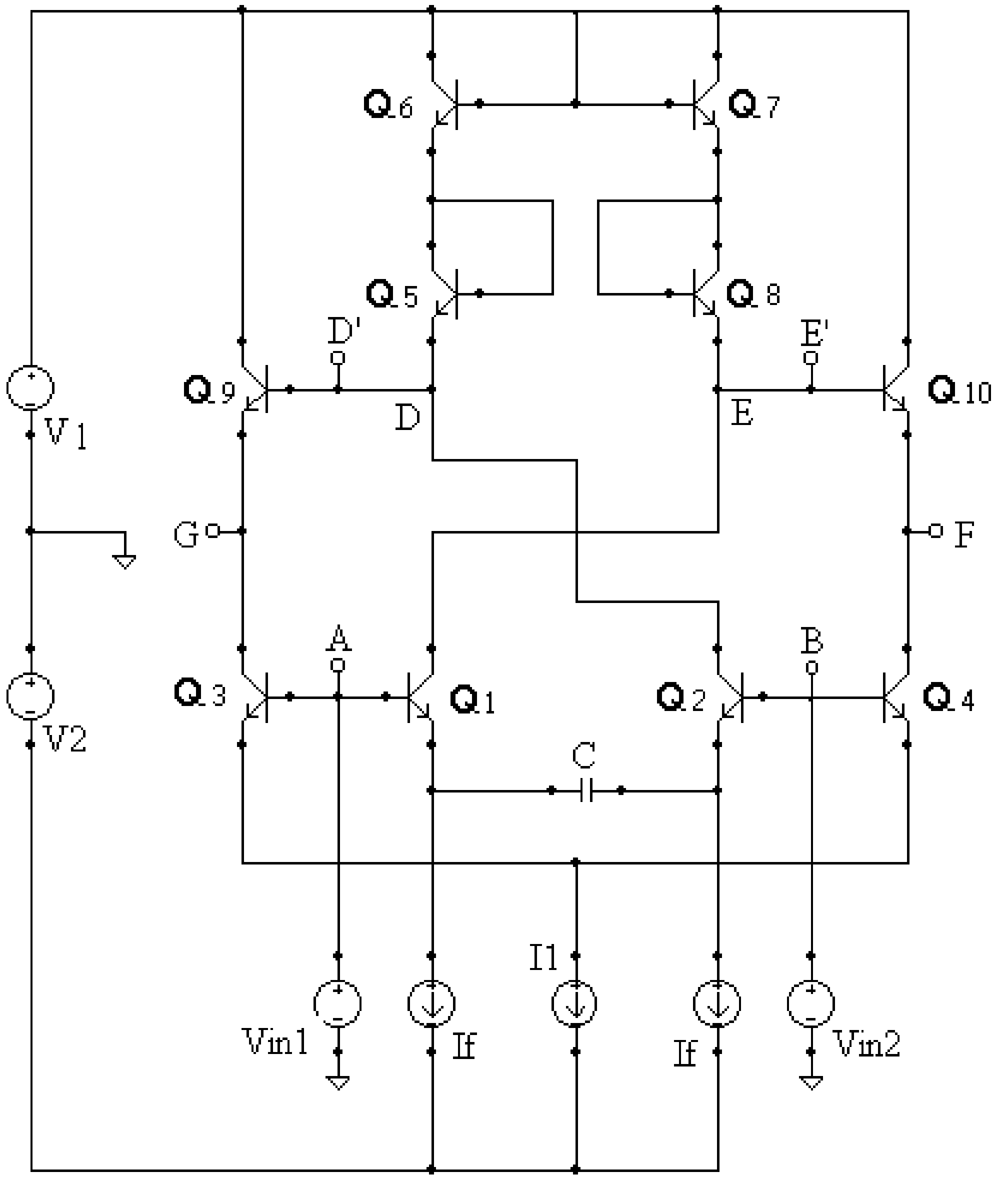

Fig. 1 Schematic diagram of the fully-balanced wide-frequency current-tunable phase-lead all-pass filter.

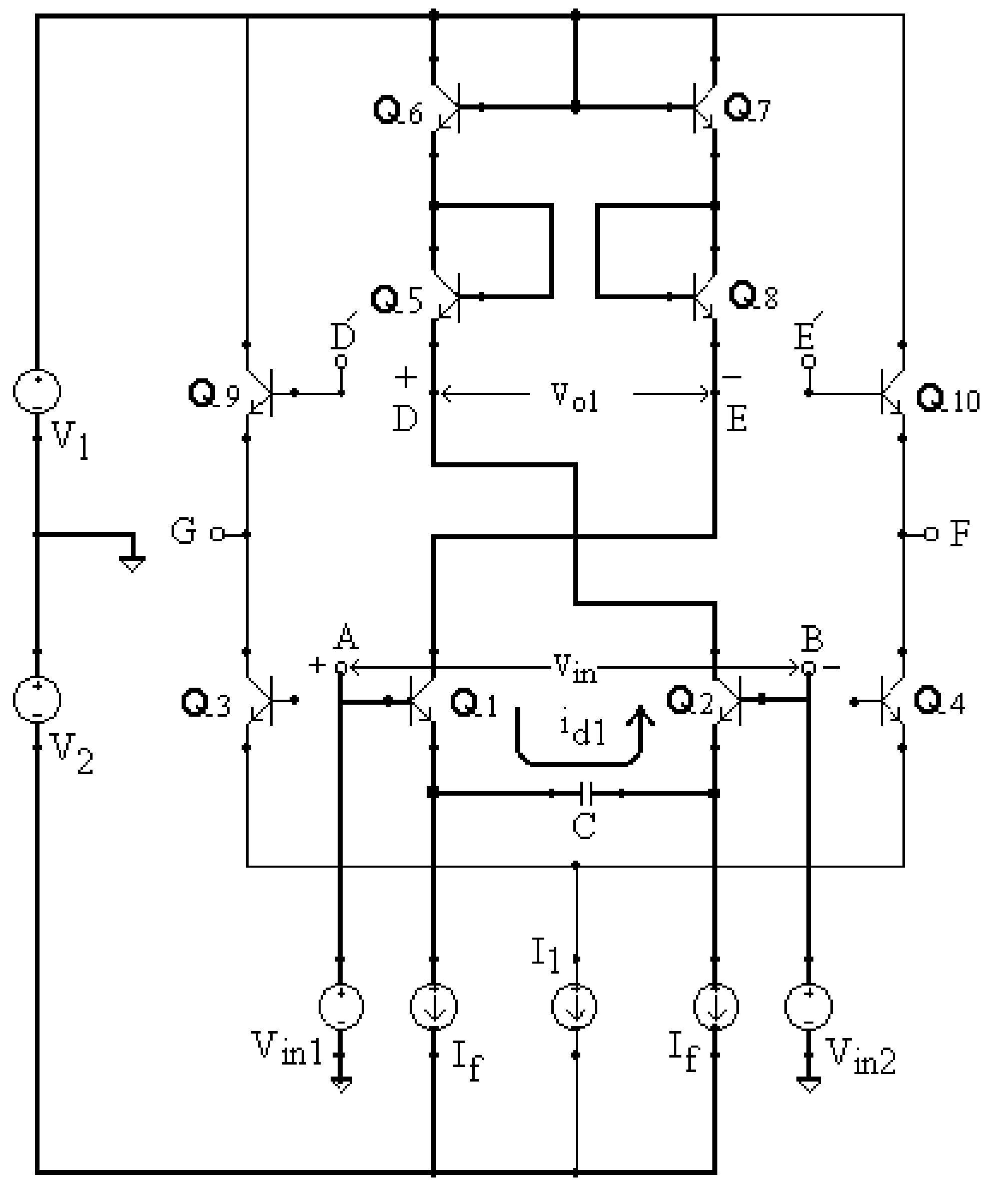

Fig. 2 Differential output current i_{d1} resulting from V_{in}.

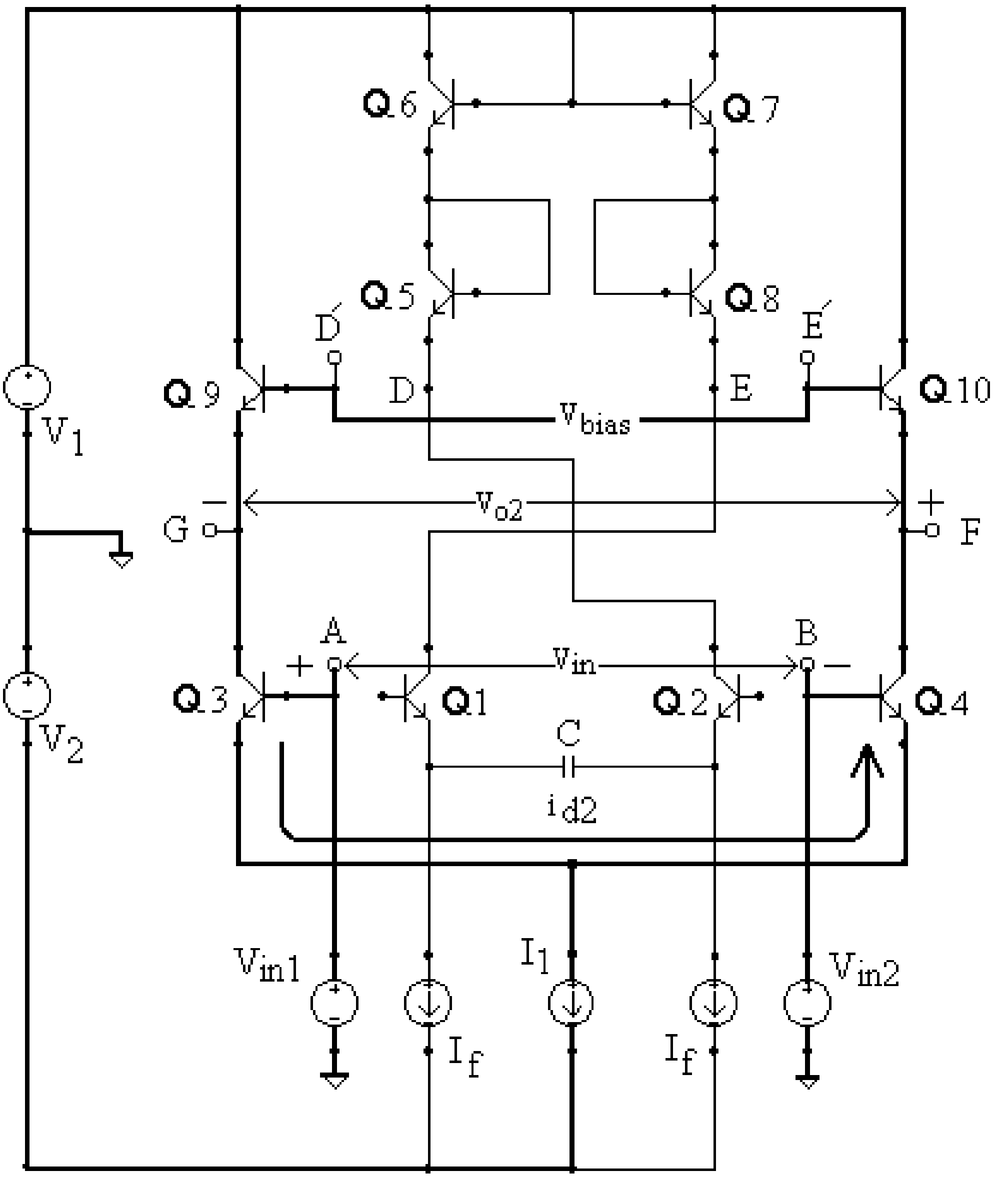

Fig. 3 Differential output current i_{d2} resulting from V_{in}.

$$i_{d1} = \frac{Cs}{1+s\tau} V_{in} \tag{1}$$

$$\tau = 2r_{e1}C = \frac{2V_T C}{I_f} \tag{2}$$

V_T is the usual thermal voltage associated with a pn junction and is approximately equal to 25 mV at room temperature. As shown in Fig. 2, the current i_{d1} passes through the loading resistance $4r_{e1}=4V_T/I_f$ formed by Q5, Q6, Q7 and Q8 between nodes D and E. The output voltage $V_{o1}=(i_{d1})(4r_{e1})$. The 1st-order transfer function V_{o1}/V_{in} therefore represents a high-pass filter of the form

$$\frac{V_{o1}}{V_{in}}=\frac{2s\tau}{1+s\tau} \tag{3}$$

In addition, V_{in} also results in a differential output current i_{d2} as shown in Fig. 3 and therefore

$$i_{d2}=\frac{V_{in}}{2r_{e2}}=\frac{V_{in}}{2V_T}\left(\frac{I_1}{2}\right) \tag{4}$$

As shown in Fig. 3, the current i_{d2} passes through the loading resistance $2r_{e2}=2V_T(2/I_1)$ formed by Q9 and Q10 between nodes F and G. The output voltage $V_{o2}=(i_{d2})(2r_{e2})$. The transfer function V_{o2}/V_{in} therefore represents a buffer of the form

$$\frac{V_{o2}}{V_{in}}=1 \tag{5}$$

By reconnecting the bases of Q9 and Q10 with nodes D and E (as shown in Fig. 1), the resulting differential, small-signal, output voltage V_o, taken across nodes G and F, is obtained through superposition and therefore $V_o=V_{o1}-V_{o2}$. Consequently, the transfer function V_o/V_{in} is of the form

$$\frac{V_o}{V_{in}}=-\left[\frac{1-s\tau}{1+s\tau}\right] \tag{6}$$

It can be seen that equation (6) represents the transfer function of a phase-lead all-pass filter [8]. The frequency ω_0 of the phase-lead all-pass filter where the magnitude and phase shift of the transfer function V_o/V_{in} are approximately 0 dB and +90 degrees, respectively, is of the form

$$\omega_0=\frac{1}{\tau}=\frac{I_f}{2CV_T} \tag{7}$$

It can be seen from equation (7) that the frequency ω_0 is tunable through the bias current I_f and hence the name “current-tunable phase-lead all-pass filter”.

4. Simulation Results

The performance of the circuit shown in Fig. 1 has been simulated using PSpice. The npn transistors are modeled by Q2N3904, where the transition frequency f_T is at 300 MHz. [9]. Fig. 4 illustrates magnitude (dB) and phase shift (degree) of V_o/V_{in} versus frequency (Hz) obtained from the simulation using, as an example, capacitor C = 0.01 μF, I_1 = 200 μA, I_f = 40 μA, 200 μA, 1mA and 5 mA. It can be seen from Fig. 4 that, for the phase shift at +90 degrees, the corresponding frequencies $f_0 = \omega_0/2\pi$ for individual values of I_f are at 12.7 kHz, 65 kHz, 320 kHz and 1.6 MHz, respectively, with the corresponding magnitude of approximately 0 dB.

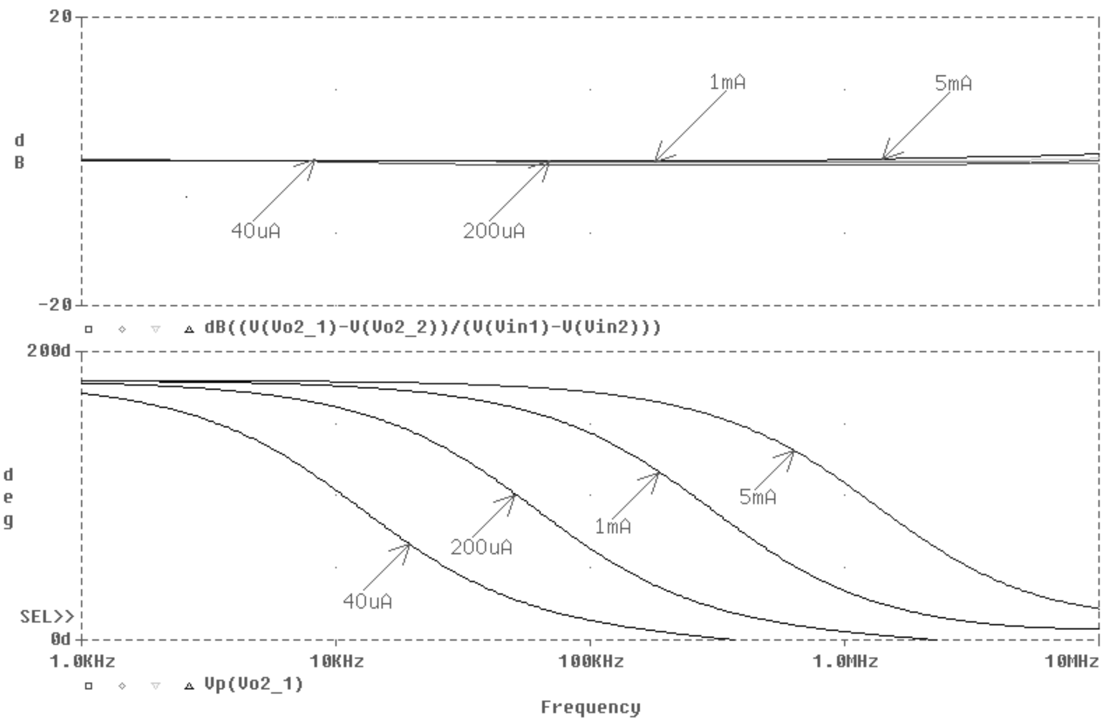

Fig. 4 Magnitude (dB) and phase shift (degree) of V_o/V_{in} versus frequency (Hz) using the capacitance C = 0.01 μF, I_1 = 200 μA and I_f = 40 μA, 200 μA, 1 mA, and 5 mA.

Fig. 5 depicts the simulation results of both the frequency $f_0 = \omega_0/2\pi$ and the corresponding magnitude (dB) of V_o/V_{in} , at the phase shift of +90 degrees, versus the bias current I_f using capacitor C = 0.01 μF and I_1 = 200 μA. For purposes of comparison, the expected (ideal) results are also included. It can be seen from Fig. 5 that both the expected and the simulated results are consistent, and the frequency f_0 is linearly current-tunable over a "wide-frequency" sweep range of approximately three orders of magnitude.

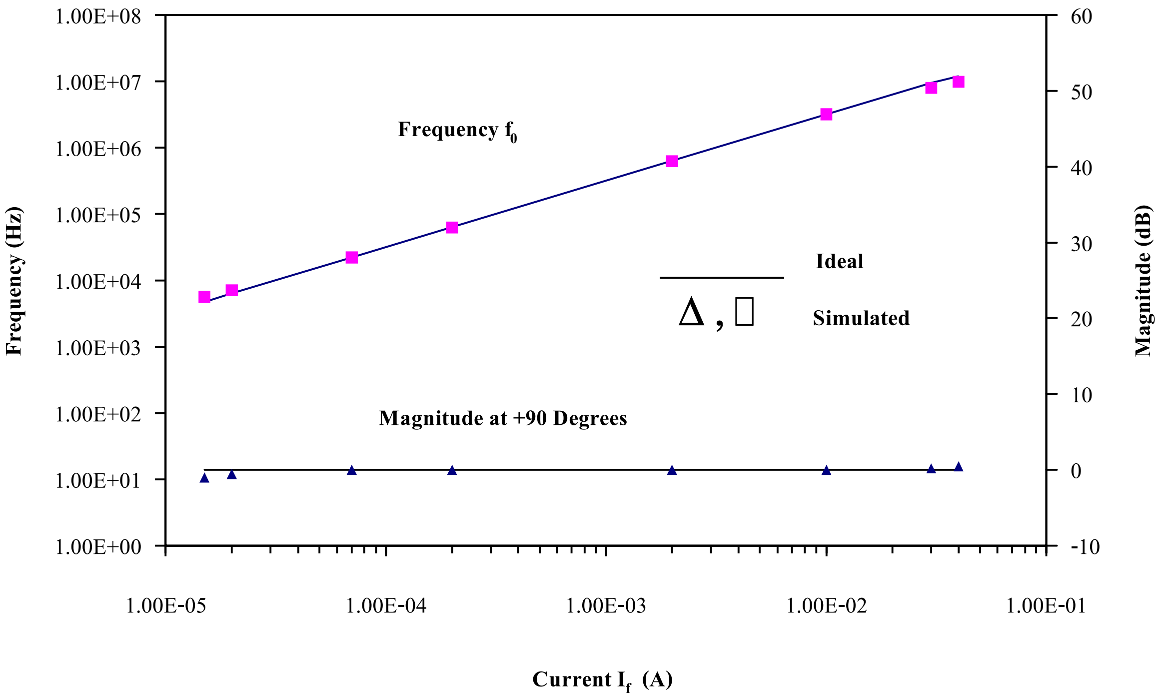

Fig. 5 Frequency f_0 and the corresponding magnitude (dB) of V_o/V_{in}, for the phase shift at +90 degrees versus the bias current I_f (A) , using a capacitance C = 0.01 μF and I_1 = 200 μA.

Fig. 6 shows the simulation results of both the frequency $f_0 = \omega_0/2\pi$ and the corresponding magnitude (dB) of V_o/V_{in} , at the phase shift of +90 degrees, versus the capacitance C, using bias current I_f = 4 mA and I_1 = 200 μA. For purposes of comparison, the expected (ideal) results are also included. It can be seen from Fig. 6 that both the expected and the simulated results are linear and consistent. By using a minimum frequency setting capacitance of 20 pF, the upper frequency f_0 can be expected at 220 MHz.

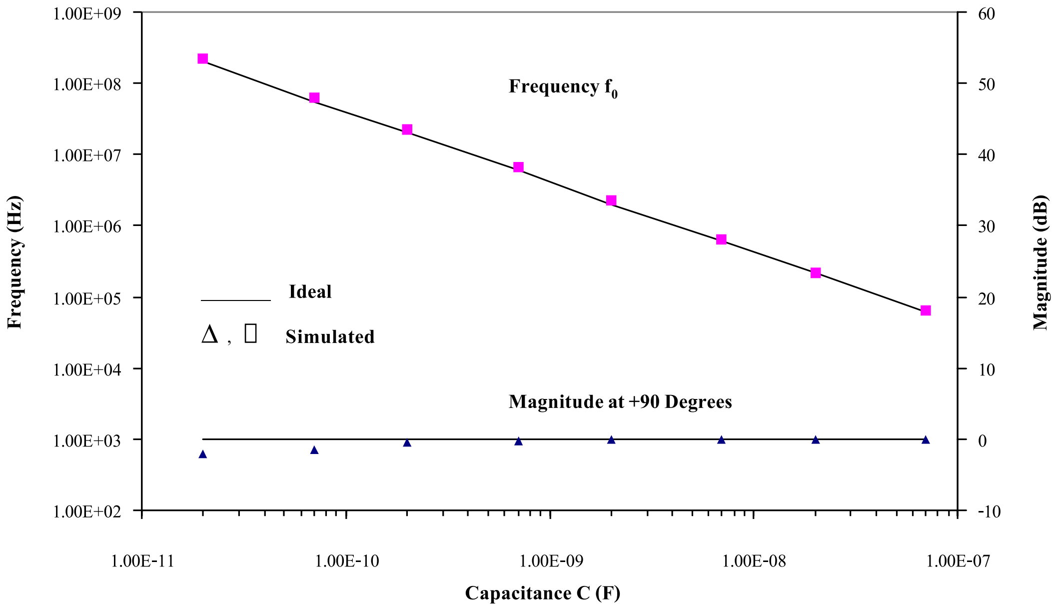

Fig. 6 Frequency f_0 and the corresponding magnitude (dB) of V_o/V_{in}, for the phase shift at +90 degrees, versus the capacitance C (F), using a bias current I_f = 4 mA and I_1 = 200 µA.

5. Discussion and Conclusions

A new integrable fully-balanced wide-frequency current-tunable phase-lead all-pass filter has been presented. The architecture of the circuit is symmetry with differential signals. The circuit is also relatively simple and integrable on-chip. Both simulated and expected results are consistent. The frequency f_0 where the magnitude and phase shift of the transfer function are approximately 0 dB and +90 degrees, respectively, is linearly current-tunable over a wide-frequency sweep range of approximately three orders of magnitude. The maximum useful frequency f_0 is approximately 220 MHz. Eq. (7) suggests that if much smaller value of C (e.g. using stray capacitance) and better transistors of much higher f_T (e.g. in the region of several GHz) are used, then much higher and more useful frequency f_0 could be expected.

Acknowledgements

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