A wideband voltage controlled operational transconductance amplifier

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Abstract : A wideband voltage controlled operational transconductance amplifier(OTA) for a high-accuracy linear voltage controlled analog systems was designed. The OTA consists of a wideband voltage-to-current converter (VIC) and conventional OTA as shown in Fig. 1. The wideband VIC using an adaptive current feedback also was designed. For verification of the performance of the proposed OTA using wideband VIC, we simulated the circuits of the commercial OTA LM13600 and OTA using conventional VIC with the same simulation condition. The simulation result shows that the proposed OTA has a control voltage range with -5.0V to 4.0V (current range with 0μA to 10mA) at supply voltage ±5.0V. The LM13600 and OTA using conventional VIC have the control voltage range with -3.6V to 5.0V and -5.0V to -2.4V, respectively.

1. Introduction

An operational transconductance amplifier(OTA) is an essential device for mixed-mode systems because it has current output, voltage input, and controllable conductance $g_m = I_B / V_T$. The V_T is thermal voltage and I_B is external controlled current [1]. Therefore, OTA is used in voltage controlled oscillators, amplifiers, filters, stereo volume control, etc. In order to control the current I_B, control voltage V_C must apply to an external resistor via I_B terminal because current can not control directly. Therefore, the converting low voltage to current can not be obtained. For high-accuracy controlled systems, voltage to current converter (VIC) converted from low voltage to high voltage is essential.

In this paper, the new VIC operating at low voltage and its application to OTA was designed. We introduce a principle for the proposed VIC and the OTA, and then discuss the results of simulation in next sections.

2. Circuit descriptions

2-1 Commercial OTA LM13600 [1]

The circuit diagram of the commercial OTA LM13600 was shown in Fig. 1. The circuit consists of differential amplifier stage composed with $Q_1 \sim Q_2$, three Wilson current mirrors for differential to single-ended current output, and one Wilson current mirror in order to bias the differential amplifier stage.

The output current for small-signal operation i_O can be written as follow ;

$$i_O = g_m (v_{IN}^+ - v_{IN}^-) = \frac{V_C - 2V_{BE} + V_{EE}}{R_1 \cdot V_T} \left(v_{IN}^+ - v_{IN}^- \right) \quad (1)$$

It notices that output current of the OTA has offset voltage of $2V_{BE}$ (about 1.4V).

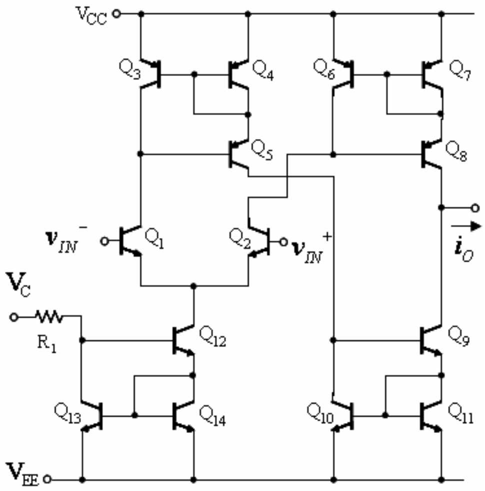


Fig. 1 Circuit diagram of the commercial OTA LM13600

2-2 Design of wideband voltage-to-current converter

The circuit diagram of the conventional and proposed wideband voltage-to-current converter (WVIC) is shown in Fig. 2(a) and (b). The conventional voltage-to-current converter (CVIC) circuit consists of cascade amplifier composed with Q_1 and Q_2 , a current mirror and voltage reference V_B . Assuming that the current mirror was identical, the output current i_{OUT} for the CVIC can be written by

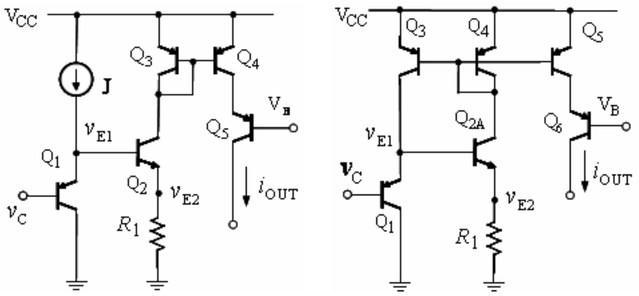
$$i_{OUT} = \frac{1}{R_1} \left(V_C + V_{T1} \ln \frac{\mathrm{J}}{\mathrm{I_{S1}}} - V_{T2} \ln \frac{i_{OUT}}{\mathrm{I_{S2}}} \right) \quad (2)$$

The WVIC shown in Fig. 2(b) has same collector current

$i_{C1} = i_{C2A} = i_{C6} (= i_{OUT})$ because of the current mirror consisting of $Q_3 \sim Q_4$ [2]-[3]. This circuit configuration provide same voltage between v_{BE1} and v_{BE2}, and then $v_E = v_C$. Assuming the current mirror was identical, the output current i_{OUT} for the WVIC can be written by

$$i_{OUT} = \frac{1}{R_1}\left(V_C + V_{T1} \ln \frac{I_{S1}}{I_{S2}} \right) \tag{3}$$

It notices that output current i_{OUT} of the WVIC is proportional to control voltage VC. The CVIC need a bias circuit but the WVIC has only controlled voltage without bias current.



(a) (b)

Fig. 2 Circuit diagram of CVIC(a) and WVIC(b)

2-3 Design of a wideband voltage controlled OTA

Two types of OTA using CVIC and WVIC were shown in Fig. 3 and 4, respectively. The complete CVIC consists of I_B, $Q_{20} \sim Q_{26}$, and R_1. The bias circuit of voltage V_B composed with I_B, $Q_{15} \sim Q_{16}$, and $Q_{23} \sim Q_{26}$. The WVIC consists of I_B, $Q_{19} \sim Q_{26}$, and R_1. The voltage V_B composed with $Q_{15} \sim Q_{16}$, and $Q_{22} \sim Q_{26}$. The core circuit of the two OTAs was that of the LM13600 shown in Fig. 1.

2-4 Design of a high linearity, wide input dynamic, and wideband voltage controlled OTA

Fig. 5 shows new high linearity, wide input dynamic, and wideband voltage controlled OTA using high linearity transconductor[3]. This curcuits consist of linear tranaconductor(I_X, Q_1~Q_8, R_E) current gain cell(Q_9~Q_{12}, R_{C1}), and the LM13600(I_Y, Q_{11}~Q_{21})[4]. If the two bias current I_X made of the proposed WVIC shown in Fig. 2(b), the output current i_{OUT} for the OTA can be written by

$$i_{OUT} = \frac{1}{R_1}\left(V_C + V_{T1} \ln \frac{I_{S1}}{I_{S2}} \right) \cdot \frac{1}{I_Y R_E}\left(v_{IN}^{+} - v_{IN}^{+} \right) \tag{4}$$

It notices that if scale current $I_{S1}=I_{S2}$, the output current of the OTA was independent with temperature V_{T1} and be proportioned to controlled voltage V_C.

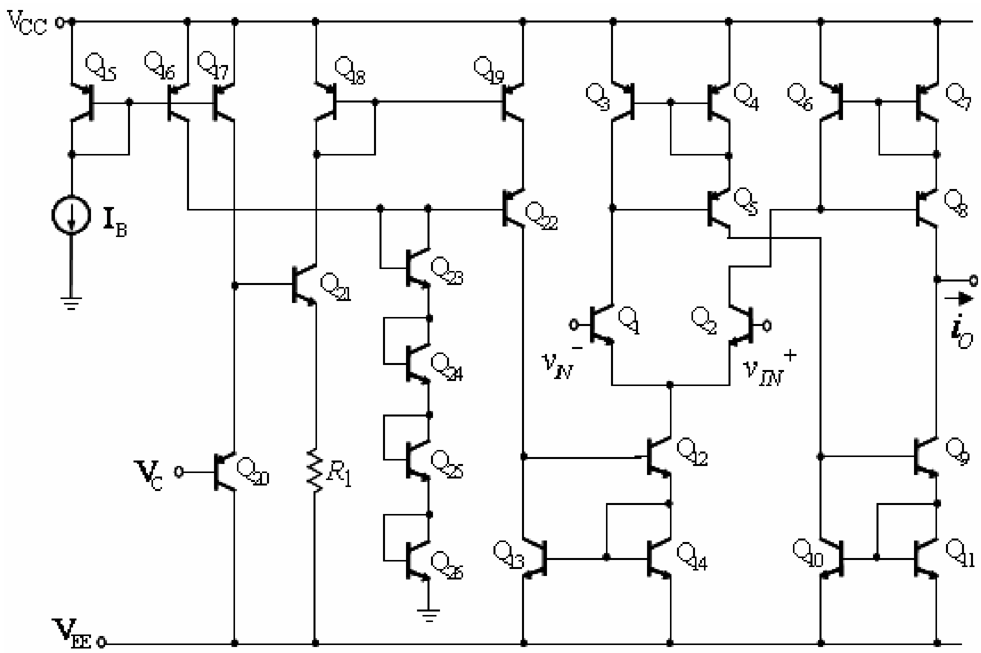


Fig. 3 Circuit diagram of the LM13600 using CVIC

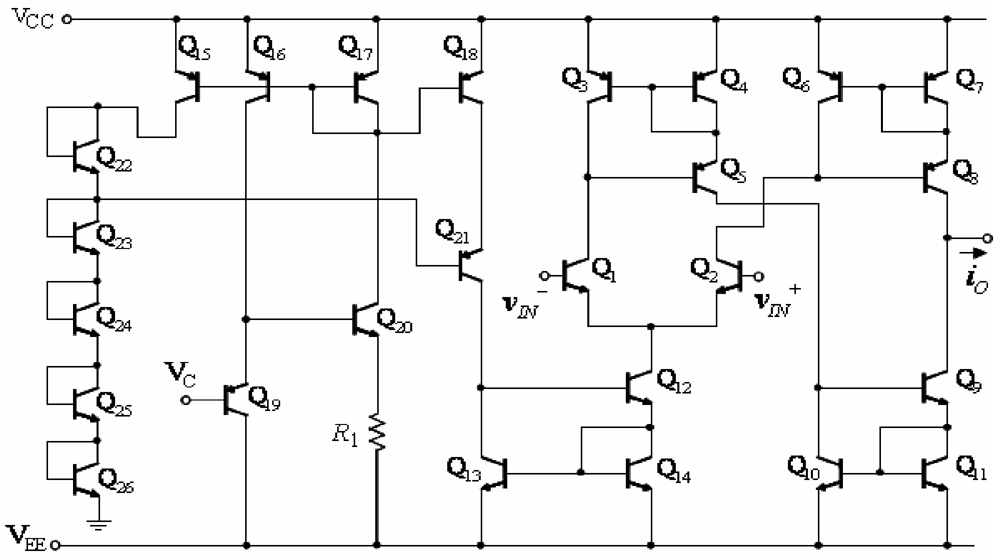


Fig. 4 Circuit diagram of the LM13600 using WVIC

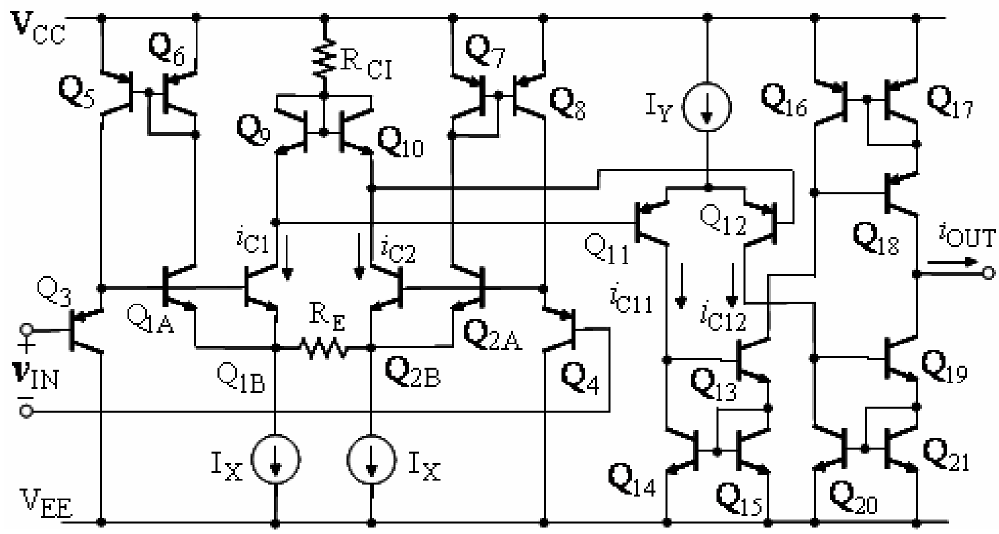


Fig. 5 Circuit diagram of high linearity, wide input dynamic, and wideband voltage controlled OTA[4]

3. Simulation results and Discussion

The operation of the proposed OTA shown in Fig. 4 was simulated by using PSPICE with commercial transistor mode parameters of Q2N3404(*npn*) and Q2N3406(*pnp*). For verification of the performance for the proposed OTA using WVIC, we simulated with the circuits of the LM13600 and the OTA using CVIC. The supply voltage V_{CC}= 5V, V_{EE}= -5V, I_B=100μA . The resistor set by $R_1 = 10\text{k}\Omega, 1\text{k}\Omega$, and 100Ω for the checking of a dynamic range.

Fig. 6 shows the transfer characteristics of input voltage versus output current for the OTA at the $R_1 = 10\text{k}\Omega$. It notices that the linear input range was ±20mV.

Fig. 7(a), (b), and (c) show the characteristics of the control voltage versus output current at $v_{IN} = 10\text{mV}$ for Fig. 1, 3, and 4, respectively. It notices that the Fig 7(a) has dynamic range with of -3.6V to 5.0V. Fig. 7(b) shows that the large output current can be limit by control voltage. Fig. 7(c) shows the characteristic of wideband voltage control. The control voltage range was -5.0V ~ 4.0V at supply voltage ±5.0V. The output current range was 0~10mA.

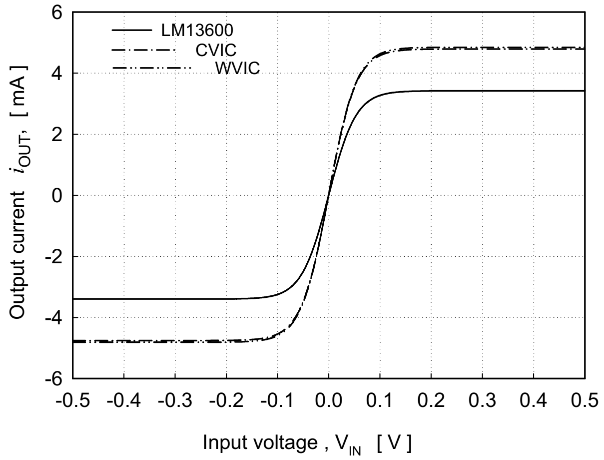
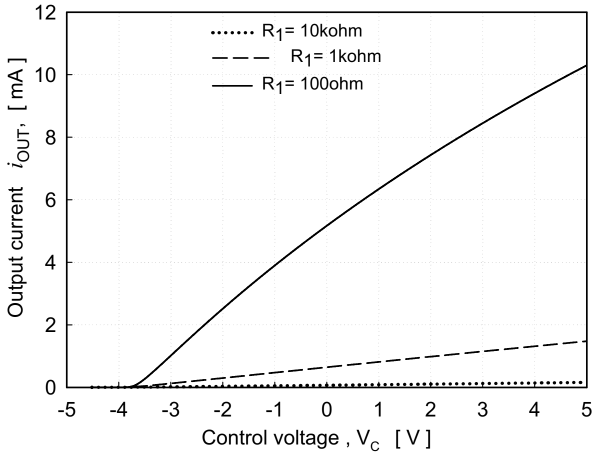
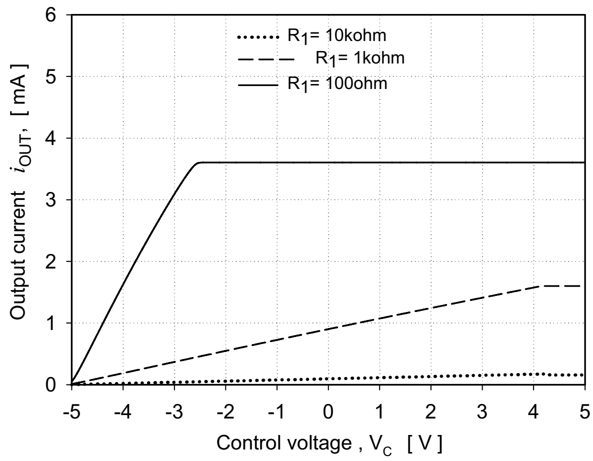


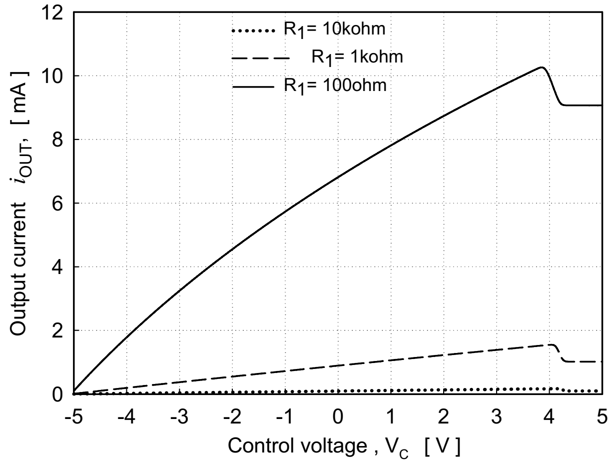
Fig. 6 Transfer characteristics of input voltage versus output current shown in Fig. 1, 3, and 4



(a)



(b)



(c)

Fig. 7 Characteristics of the control voltage versus output current ; LM13600(a), CVIC(b), and WVIC(c)

4. Conclusions and future subject

A wideband voltage controlled operational trans-conductance amplifier (OTA) for a high-accuracy linear voltage controlled analog systems was presented. Simulation has demonstrated that the circuit has the characteristics of wideband voltage control. Therefore, the proposed OTA will be useful for building block of accuracy voltage control systems. Now, we simulate and optimize the OTA using the fabrication model parameters. In the future, we will fabricate chip by bipolar process.

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