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Positive current output OTA-based first-order APSs

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Abstract: *This paper introduces voltage-mode and current-mode first-order all pass sections (APSs) employing positive current output operational trans-conductance amplifiers (OTAs) and grounded capacitor. The circuits enable all pass characteristics by choosing the current output of the OTA. Additionally, the circuit parameters ω_0 and H can be set independently through adjusting the bias currents of the OTAs electronically. Some examples are given together with simulation results by PSPICE.*

Keywords: *active circuit, all pass characteristic, OTA, CMOS technology*

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I. Introduction

High performance active circuits have received much attention. The circuit designs employing active devices such as the OTAs, second generation current conveyors (CCIIs), differential voltage current conveyors (DVCCs) and operational trans-resistance amplifiers (OTRAs) have been reported in the literature [1]-[10].

An OTA is a very useful active device, and OTA-based circuit has electronic tuning capability for circuit responses by the bias currents. The circuit designs with the OTA performances have been discussed in the past [1]-[3]. There are two kinds of the OTA. One is positive current output OTA, another is negative current output one. The positive current output OTA is composed of a simpler circuit configuration than the negative current output one. Hence it has a wide band operation and low power performance compared with the negative current output OTA.

An APS is a very useful function block for realizing phase shifter, phase equalizer, oscillator and so on. The APS designs using the CCII, DVCC and differential difference current conveyor (DDCC) have been discussed [4]-[10]. However the APS based on the positive current output OTAs hasn't been studied sufficiently. In addition, the electronic and independent tuning capabilities for the circuit parameters ω_0 and H are needed.

This paper introduces electronically tunable voltage-mode and current-mode first-order APSs using three positive current output OTAs and one grounded capacitor. The circuits enable the all pass characteristics by choosing the current output of the OTA. Additionally, the circuit parameters ω_0 and H can be set independently through adjusting the bias currents of the OTAs. It is made clear from sensitivity analysis that the APSs have very low sensitivities with respect to the circuit active and passive components.

Some examples are given together with simulation results by PSPICE. The workability was confirmed.

II. OTA

Figure 1 shows the symbol for the positive current output OTA. This shows dual current output OTA.

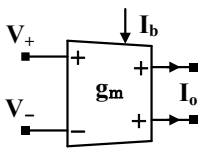

Figure 1: Symbol for OTA

The current output I_o is given by:

$$I_o = g_m(V_+ - V_-) \qquad (1)$$

where g_m denotes the trans-conductance gain.

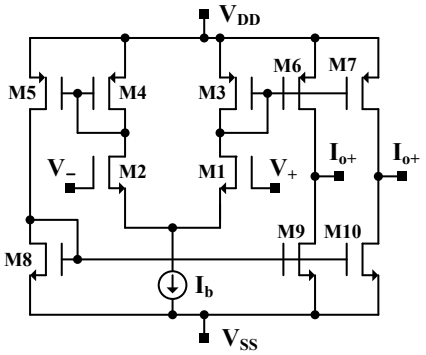

Figure 2: Positive current output OTA with MOS transistors

The positive current output OTA with MOS transistors [2] is shown in Fig.2. The trans-conductance gain can be characterized by:

$$g_m = \sqrt{\mu_n C_{ox} \frac{W}{L} I_b} \qquad (2)$$

where μ_n, C_{ox}, W/L and I_b are the electron mobility of NMOS, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively. It is found that the trans-conductance gain is adjustable by a supplied bias current I_b.

III. Circuit configuration and analysis

Figure 3 shows basic current-mode APS configuration. The circuit is constructed with one positive current output OTA and grounded capacitor.

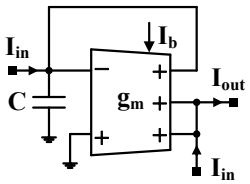

Figure 3: Basic current-mode APS configuration

Routine analysis yields the circuit transfer function T(s)(=$I_{out}(s)/I_{in}(s)$) given by:

$$T(s) = \frac{-1 + sC/g_m}{1 + sC/g_m} \qquad (3)$$

Figure 4 shows voltage-mode APS configuration. The circuit is constructed with three positive current output OTAs and one grounded capacitor.

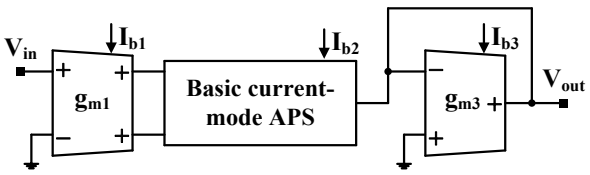

Figure 4: Voltage-mode APS configuration

The circuit transfer function T(s)(=$V_{out}(s)/V_{in}(s)$) is given by:

$$T(s) = \frac{g_{m1}(-1+sC/g_{m2})}{g_{m3}(1+sC/g_{m2})} \qquad (4)$$

The circuit parameters ω_0 and H can be expressed as:

$$\omega_0 = \frac{g_{m2}}{C}, \quad H = \frac{g_{m1}}{g_{m3}} \qquad (5)$$

The parameter ω_0 can be set by g_{m2} and C. The parameter H is able to be set electronically by g_{m1} and g_{m3} without disturbing ω_0. Therefore, this circuit has independent tuning capability for the circuit parameters.

The phase response is given by:

$$\theta = \pi - 2\tan^{-1}(\omega C/g_{m2}) \qquad (6)$$

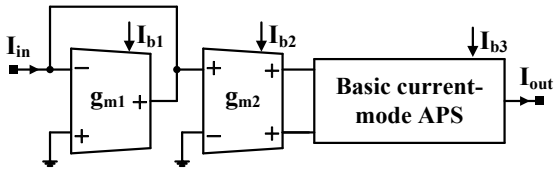

Figure 5: Current-mode APS configuration

Figure 5 shows current-mode APS configuration. The circuit transfer function T(s)(=$I_{out}(s)/I_{in}(s)$) is given by:

$$T(s) = \frac{g_{m2}(-1+sC/g_{m3})}{g_{m1}(1+sC/g_{m3})} \qquad (7)$$

The circuit parameters ω_0 and H become:

$$\omega_0 = \frac{g_{m3}}{C}, \quad H = \frac{g_{m2}}{g_{m1}} \qquad (8)$$

It is found from equation above that the circuit parameters ω_0 and H can be tuned independently like as the voltage-mode ones.

The phase response θ is given by:

$$\theta = \pi - 2\tan^{-1}(\omega C/g_{m3}) \qquad (9)$$

We consider below the deviations of the circuit components on the circuit characteristic. Table 1 shows the sensitivities with respect to the circuit components (g_{m1}, g_{m2}, g_{m3} and C). We can find from these values that the APSs enjoy very low sensitivities to the circuit components. It is also noted that the sensitivities do not depend upon the circuit component values.

Table 1 Sensitivity to circuit components.

(a) voltage-mode APS

x	ω_0	H
g_{m1}	0.0	1.0
g_{m2}	1.0	0.0
g_{m3}	0.0	-1.0
C	-1.0	0.0

(b) current-mode APS

x	ω_0	H
g_{m1}	0.0	-1.0
g_{m2}	0.0	1.0

g_{m3}	1.0	0.0
C	-1.0	0.0

IV. Design example and simulation results

To verify the theoretical analysis, the APSs were simulated using PSPICE simulation program. As a design example, we consider voltage-mode circuit characteristic with the cut-off frequency f_0 (=$\omega_0/2\pi$)=1MHz and gain constant H=2.0. In the simulation, we have used the macro model of the OTA shown in Fig.2.

To realize the all pass characteristic above, we have determined that the bias currents of the OTAs and capacitor were $I_{b1}=I_{b3}=62.0\mu A$, $I_{b2}=15.5\mu A$ and C=20pF, respectively. The input voltage and supplied voltages of the OTA were $V_{in}=100mV$ and $V_{DD}= -V_{SS}=1.80V$.

Figure 5 shows the simulation responses of the voltage-mode APS. They are sufficiently favorable over a wide frequency range. The power dissipation of the APS was 2.49mW.

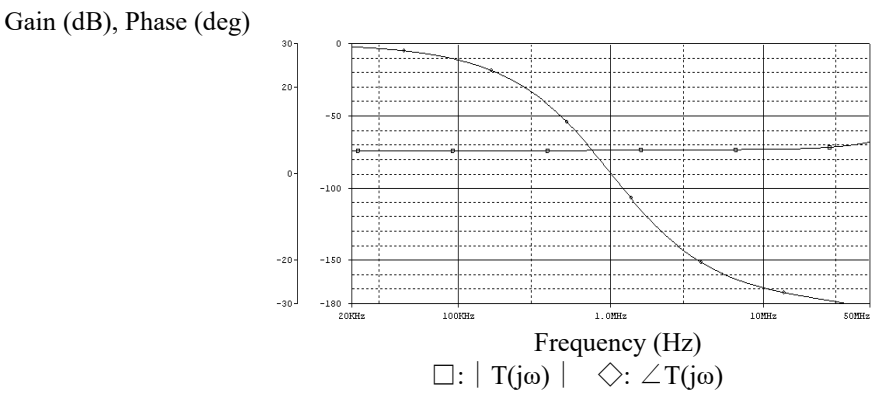

Figure 5: Voltage-mode simulation responses

Figure 6 shows the simulation responses of the current-mode APS with f_0=1MHz and H=1.0. In the case, we have determined that the bias currents and capacitor were $I_{b1}=I_{b2}=I_{b3}=62.0\mu A$ and C=20pF, respectively. The input current and supplied voltages of the OTA were $I_{in}=10\mu A$ and $V_{DD}=-V_{SS}=1.80V$. They are good enough over a wide frequency range. In this case, the power dissipation was 3.24mW.

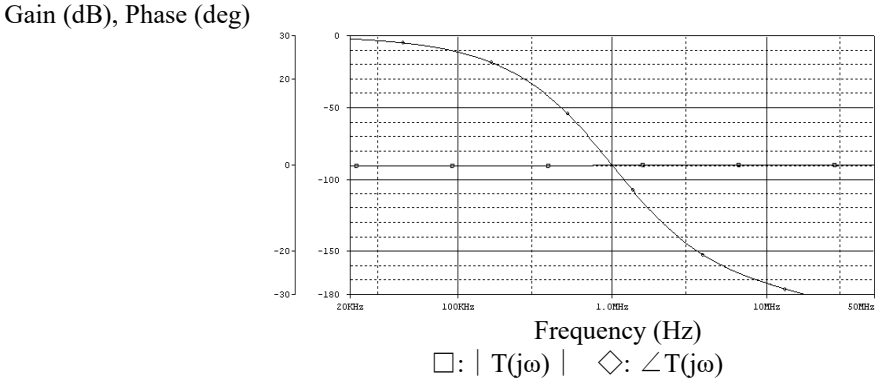

Figure 6: Current-mode simulation responses

In this simulation, the dimensions of OTA were set as W=4μm and L=2μm. Additionally, we have used the model parameters of 0.5μm MOS technology obtained through MOSIS.

V. Conclusion

Electronically tunable voltage-mode and current-mode first-order APSs using positive current output OTAs and grounded capacitor have been proposed. We have demonstrated that the circuits enable all pass characteristic, and that the circuit parameters can be tuned independently by the bias currents of the OTAs. It has been made clear from sensitivity analysis that the APSs enjoy good sensitivity performance with respect to

the circuit active and passive components. The simulation responses have been favorable over a wide frequency range. The proposed circuits have some advantages (i.e. wide band operation, low power performance, independent tuning capability for circuit parameters). The circuit configurations are very suitable for implementation in CMOS technology.
The non-idealities of the OTA affect the circuit characteristic. A solution on this must be discussed further.

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