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Electronically tunable OTA-based first-order APSs

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Abstract: *This paper introduces electronically tunable voltage-mode and current-mode first-order all pass sections (APSs) employing operational trans-conductance amplifiers (OTAs) and grounded capacitor. The circuits can enable two 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 simulated 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]-[8].

It is well known that the OTA provides highly linear electronic tunability and wide tunable range of its trans-conductance gain. The circuit designs with the OTA performances have been discussed in the past [1]-[3].

An APS is a very useful function block for realizing phase shifter, phase equalizer and oscillator and so on. The APS designs using the CCII, DVCC and differential difference current conveyor (DDCC) have been discussed [4]-[9]. However, as several APSs [4]-[6] use ungrounded passive components, it is not a desired property for IC implementation [8]. Although other circuits [7]-[9] employ only grounded passive components, these circuits have no independent tuning capability for the circuit parameters ω_0 and H. In addition, the gain constant is unity in all circuits. It is required an additional device to supply the desirable gain constant. The circuit [10] employing the OTA and unity gain differential amplifier has electronic tuning capability for circuit parameter ω_0. However, the gain constant is unity. APSs with the performances (i.e. electronic and independent tuning capabilities for the circuit parameters ω_0 and H) above have not yet been studied sufficiently.

This paper introduces electronically tunable voltage-mode and current-mode first-order APSs using three OTAs and one grounded capacitor. The circuits can enable two 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 simulated results by PSPICE. The workability was confirmed.

II. OTA

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

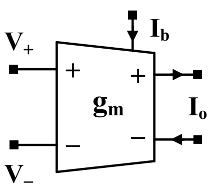


Figure 1: Symbol for OTA

The current output I_o is given by:

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

where g_m denotes the trans-conductance gain.
In (1), the sign ± shows the polarity of the current output.

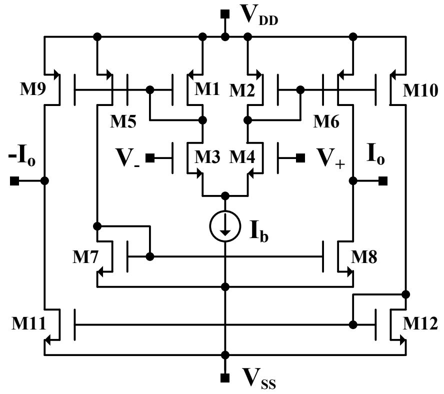


Figure 2: OTA with MOS transistors

The 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 voltage-mode APS configuration. The circuit is constructed with three OTAs and one grounded capacitor. The sign ± in the OTA shows plus or minus polarity of the current output.

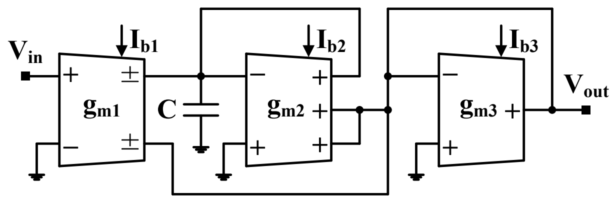


Figure 3: Voltage-mode APS configuration

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

$$T(s) = \pm \frac{g_{m1}(-1 + sC/g_{m2})}{g_{m3}(1 + sC/g_{m2})} \qquad (3)$$

The circuit parameters ω_0 and H can be expressed as:

$$\omega_0 = \frac{g_{m2}}{C}, \quad H = \frac{g_{m1}}{g_{m3}} \qquad (4)$$

The parameter ω_0 can be set by g_{m2} and C. The parameter H can also 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 responses are given by:

$$\theta_p = \pi - 2\tan^{-1}(\omega C / g_{m2}) \qquad (5)$$

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

In (5) and (6), θ_p shows the phase response in the case of the plus current output of the first stage OTA, while θ_n shows the response in the minus current output. The phase θ_p takes the value of from π to 0 with the angular frequency ω. And the phase θ_n takes the value of from 0 to $-\pi$.

Figure 4 shows current-mode APS configuration. The circuit transfer function $T(s)(=I_{out}(s)/I_{in}(s))$ is given by:

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

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 one.

The phase responses are given by :

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

$$\theta_n = -2\tan^{-1}(\omega C / g_{m3}) \qquad (10)$$

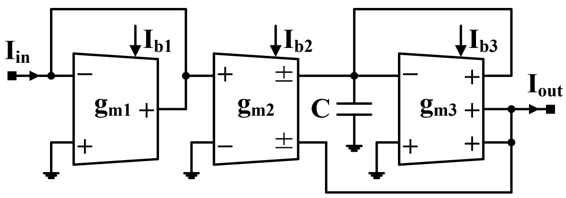


Figure 4: Current-mode APS configuration

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	$S_x^{\omega_0}$	S_x^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

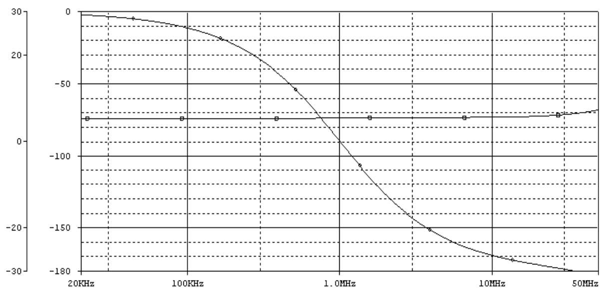
x	$S_x^{\omega_0}$	S_x^H
g_{m1}	0.0	-1.0
g_{m2}	0.0	1.0
g_{m3}	1.0	0.0
C	-1.0	0.0

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 $I_{b1}=I_{b3}$=62.0μA, I_{b2}=15.5μA and C=20pF, respectively. The input voltage and supplied voltages of the OTA were V_{in}=100mV and $V_{DD}=-V_{SS}$=1.80V.

Gain (dB), Phase (deg)

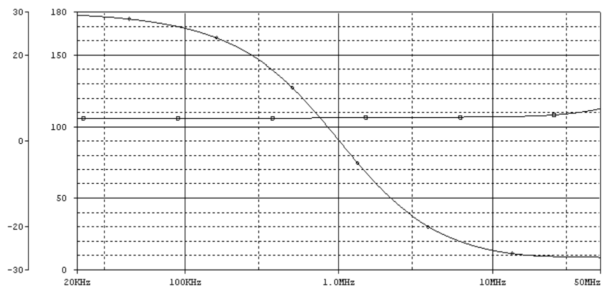


Frequency (Hz)

□: │T(jω)│ ◇: ∠T(jω)

(a)

Gain (dB), Phase (deg)



Frequency (Hz)

□: │T(jω)│ ◇: ∠T(jω)

(b)

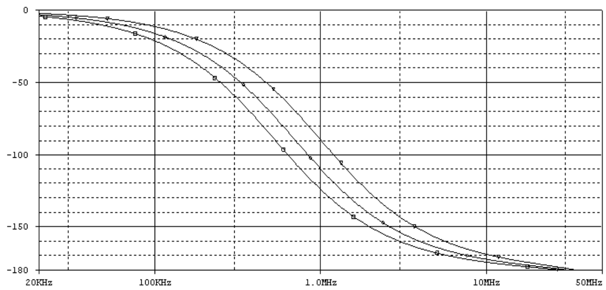
Figure 5: Voltage-mode simulation responses ((a) plus current output, (b) minus current output)

Figure 5 (a) shows the simulation responses of the voltage-mode APS in the case of the plus current output. The response in the minus current output is shown in Fig.5 (b). They are sufficiently favorable over a wide frequency range. The power dissipation of the APS was 2.49mW.

Figure 6 shows the voltage-mode phase responses with f_0-tuning (i.e. f_0=500kHz, 700kHz and 1MHz), keeping H=1.0. In this case, the bias currents were $I_{b1}=I_{b3}$=62.0μA, I_{b2}=13.6μA, 28.2μA and 62.0μA, respectively. It is found that the cut-off frequency f_0 can be tuned electronically by the bias currents.

Figure 7 shows the input and output waveforms. The input voltage and frequency were set as V_{in}=100mV and f =1MHz. The total harmonic distortion (THD) of the output waveform was 0.1128%. It is found that the waveform has very low distortions.

Phase (deg)

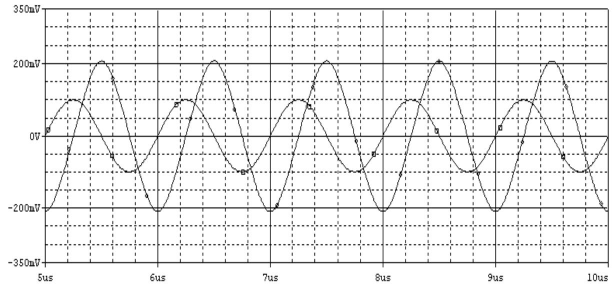


Frequency (Hz)

□: f_0=500kHz ◇: f_0=700kHz ▽: f_0=1MHz

Figure 6.:Voltage-mode f_0-tuning responses

V_{out} (mV)



Time (μs)

□: V_{in} ◇: V_{out}

Figure 7: Voltage-mode input and output waveforms

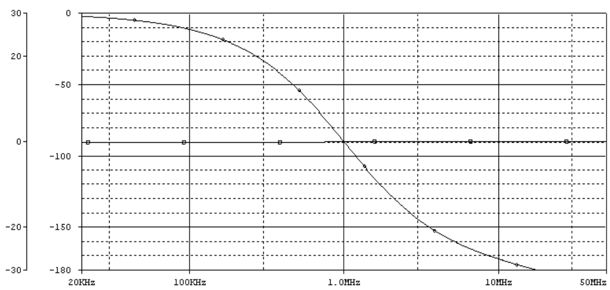
Figure 8 shows the simulation responses of the current-mode APS with f_0=1MHz and H=1.0. In the case, we have determined that the bias currents and capacitor were $I_{b1}=I_{b2}=I_{b3}$=62.0μA and C=20pF, respectively. The input current and supplied voltages of the OTA were I_{in}=10μA and $V_{DD}=-V_{SS}$=1.80V. They are good enough over a wide frequency range. In this case, the power dissipation was 3.24mW.

Figure 9 shows the input and output waveforms. The input current and frequency were set as I_{in}=10μA and f =1MHz. The THD of the current output was 0.1126%.

Figure 10 shows the current-mode phase responses with f_0-tuning (i.e. f_0=500kHz, 700kHz and 1MHz), keeping H=1.0. In this case, the bias currents were same for the voltage-mode APS. The cut-off frequency f_0 can also be tuned electronically by the bias currents like as the voltage-mode one.

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.

Gain (dB), Phase (deg)

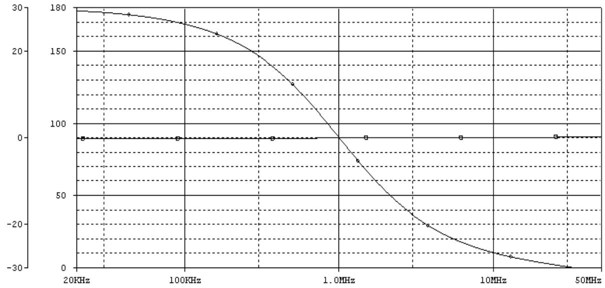


Frequency (Hz)

□: │T(jω)│ ◇: ∠T(jω)

(a)

Gain (dB), Phase (deg)



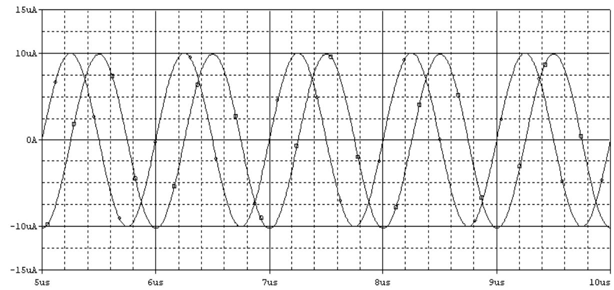
Frequency (Hz)

□: │T(jω)│ ◇: ∠T(jω)

(b)

Figure 8: Current-mode simulation responses ((a) plus current output, (b) minus current output)

I_{out} (μA)

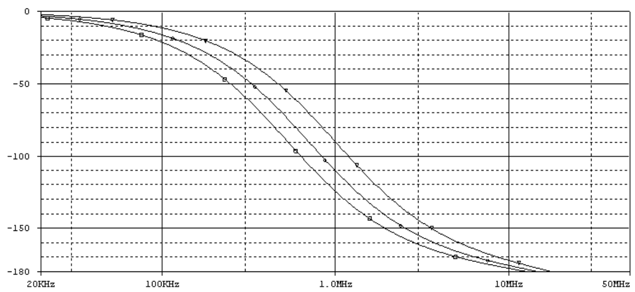


Time (μs)

□: I_{in} ◇: I_{out}

Figure 9: Current-mode input and output waveforms

Phase (deg)



Frequency (Hz)

□: f_0=500kHz ◇: f_0=700kHz ▽: f_0=1MHz

Figure 10: Current-mode f_0-tuning responses

V. Conclusions

Electronically tunable voltage-mode and current-mode first-order APSs using OTAs and grounded capacitor have been proposed. We have demonstrated that the circuits can enable two all pass characteristics by choosing the current output of the OTA, 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 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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