NOVEL CURRENT-MODE QUOTIENT CIRCUIT

MUHAMMAD TAHER ABUELMA'ATTI

King Fahd University of Petroleum and Minerals, Box 203, Dhahran 31261, Saudi Arabia

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A novel current-mode quotient circuit is presented. The circuit uses available devices. Effects of non-ideal active-elements are considered.

INTRODUCTION

In current-mode signal processing circuits the current rather than the voltage is used as the active variable either throughout the whole circuit or in certain critical areas. This can result in wider bandwidth, greater linearity, and larger dynamic range than in voltage mode circuits [1, 2]. This justifies the large number of publications reporting various current-mode implementations (see for example [3–9]). No attempt however has been reported to implement a current-mode “one-over” circuit or more generally a current-mode quotient circuit. The transfer function of a current-mode quotient circuit is said to be ideal or accurate if the output current is linearly proportional to the quotient of two input currents. The transfer function of a current-mode “one-over” circuit is said to be ideal or accurate if “one over the output current” is linearly proportional to the input current. It is the purpose of this paper to present a current-mode quotient circuit that can also implement a current-mode “one-over” operation. These operations are very useful in a wide range of applications.

PROPOSED CIRCUIT

Consider the circuit shown in Fig. 1. Assuming that the second-generation current conveyor (CCII) is ideal with $v_x = v_y$, $i_y = 0$ and $i_x = i_z$, and that the operational transconductance amplifier is ideal with $i_d = g_m(v_a - v_b)$, where $g_m = I_1/2V_T$, V_T is the thermal voltage and I_1 is the auxiliary bias current of the OTA, then with an ideal buffer, $v_b = v_i$, where v_b and v_i are the output and input voltages of the buffer, it is easy to show that the output current I_z can be expressed as

$$I_z = \frac{2V_T}{R} \frac{I_1}{I_2} \quad (1)$$

FIGURE 1 Proposed Current-Mode Quotient Circuit.

Equation (1) shows that the output current I_z is linearly proportional to the quotient of the two input currents I_1 and I_2 . Thus, the circuit of Fig. 1 can work as a current-mode quotient circuit.

Now, by obtaining the current I_1 from a constant current source, it is easy to see that the proposed circuit can work as a current-mode “one-over” circuit. Thus, a possible realization of a current-mode “one-over” circuit can be as shown in Fig. 2. This is a modified version of the bandgap voltage reference circuit [10]. Assuming that $R_A = R_B$ and an ideal operational amplifier (OA) with infinite gain, $v_p = v_n$, then

$$I_A = I_B = V_T \ln(n)/R_2 \quad (2)$$

where n is the ratio between emitter areas of the two transistors Q_1 and Q_2 . Thus, the current I_1 will be given by

$$i_d = (I_A + I_B) \quad (3)$$

Combining (1)–(3), routine analysis, using $v_x = v_y$ and, $i_x = i_z$ yields

$$\frac{1}{I_o} = \alpha I_i \quad (4)$$

where $\alpha = RR_2/(2V_T)^2 \ln(n)$. Equation (4) indicates that the realization of a current-mode “one-over” circuit is feasible.

The input impedance of the OTA may have a significant effect over the performance of the proposed circuit. Although it is possible to predict that influence, it is more practical to buffer the OTA input as shown in Fig. 1. Buffers may be non-ideal, however. A non-ideal buffer with slight gain deviation can be described by $\nu_b = (1 - \lambda)\nu_i$, where $\lambda \ll 1$. The effect of the non-ideal CCII characteristic on the performance of the circuit of Fig. 1 can be studied using the simplified model shown in Fig. 3. This simplified model was deduced from [11]. Due to the high values of R_Y and R_Z and low values of C_Y and C_Z , the effects, that have to be considered are principally due to ϕ_i , ϕ_v , and r_{XY} . Assuming that the current transfer ratio and the voltage gain of a non-ideal CCII can be described by $\phi_i = i_Z/i_X$, $\phi_v = \nu_X/\nu_Y$ where $\phi_i = 1 + \varepsilon_i$, $|\varepsilon_i| \ll 1$ and $\phi_v = 1 + \varepsilon_v$, $|\varepsilon_v| \ll 1$, reanalysis of the circuit of Fig. 1 yields the modified output current I_o

$$\frac{1}{I_o} = \alpha \left(1 + \frac{r_{XY}}{R} \right) (1 - \lambda)(1 + \varepsilon_i)(1 + \varepsilon_v) I_i \quad (5)$$

Since the parasitic resistance r_{XY} is of the order of 10–100 Ohm [12], and if we choose $r_{XY} \ll R$, then after neglecting second-order terms, (5) reduces to

$$\frac{1}{I_o} = \alpha \left(1 + \frac{r_{XY}}{R} - \lambda + \varepsilon_i + \varepsilon_v \right) I_i \quad (6)$$

Equation (6) shows that the output current will be affected by the buffer and CCII non-idealities. However, the error term in (6), $\left(1 + \frac{r_{XY}}{R} - \lambda + \varepsilon_i + \varepsilon_v \right)$, contains positive and negative terms and cancellation of the effects of CCII and buffer non-idealities is, therefore, feasible. Thus, if $r_{XY}/R + \varepsilon_i + \varepsilon_v = \lambda$, (6) reduces to (4); that is, the input current-output current characteristic of the proposed “one-over” circuit is unchanged even with a non-ideal buffer and CCII. Moreover, by proper selection of the resistors R_A and R_B , the effect of the finite gain of the operational amplifier can be compensated. Therefore, an ideal “one-over” transfer function can be realised even with a non-ideal operational amplifier, buffer, operational transconductance amplifier, and second-generation current conveyor.

FIGURE 3 Simplified model of CCII+.

CONCLUSION

A simple current-mode quotient and “one-over” circuit has been presented. By proper selection of the parameters, the effects of a non-ideal operational amplifier, buffer, operational transconductance, and second-generation current conveyor may cancel each other. Thus, the realization of an ideal current-mode “one-over” transfer function is feasible, even with non-ideal active components. It is worth mentioning here that the influence of temperature on g_m of commercial OTAs like CA3080 can be compensated by using temperature-compensated OTAs [13–14]. Also, implementations using CMOS OTAs makes feasible the use of relatively large input voltage swings [15–17]. Thus, the major limitations of commercial OTAs like CA3080 can be avoided.

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