Gain Constant Adjustment Facility in Active Circuits

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Abstract -- **Starting from a general dual input single operational amplifier (OA) circuit, we obtain a difference amplifier and a single input circuit. The gain constant adjustment facility is provided by adding one resistor in the latter category of circuits. The technique is demonstrated with a difference amplifier, an active bridge circuit, first and second order all pass filters. The proposed circuits are better suited for fabrication both in discrete and integrated forms. OA is replaced by some well-known active devices.**

Keywords: Active RC all-pass filters, Gain constant, Difference amplifier, Wheatstone bridge

I. INTRODUCTION

Very recently, Dutta Roy [1] proposed an RC active first order all-pass filter using a finite gain difference amplifier (FGDA). Though he confined himself to the first order all-pass filter using *op-amp*, he did not consider at all the realization of FGDA using OA. We have given a general dual input circuit and derived the circuit for FGDA in Section 2 (Case A). Case B deals with the single input circuit. We have introduced an active bridge. Gain constant (GC) adjustment technique is described in section 3. Its functioning is demonstrated by applying it to a difference amplifier, and first and second-order all-pass filters. Section 4 gives the conclusions.

II. A GENERAL DUAL-INPUT CIRCUIT

Consider the general dual input circuit shown in Fig. 1 where N is a 3-terminal network with the voltage transfer function (VTF) $T_N(s)$.

By superposition theorem the output voltage

$$V_o = [T_N(s)(1+m)V_1 - mV_2] \tag{1}$$

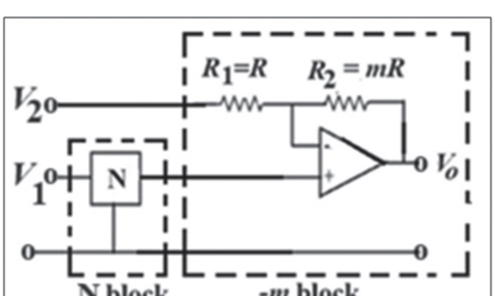


Figure 1. A general dual input circuit.

Case A

Let us replace N by a potential divider circuit shown in Fig. 2.

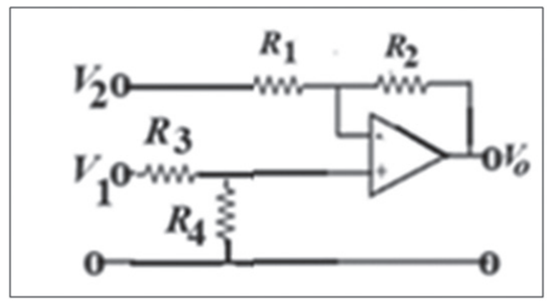


Figure 2. A difference amplifier.

or

$$V_o = \left[\left(\frac{R_4}{R_3+R_4}\right)\left(1+\frac{R_2}{R_1}\right)V_2 - \left(\frac{R_2}{R_1}\right)V_1\right]. \tag{2}$$

Let

$$\left(\frac{R_4}{R_3+R_4}\right)\left(1+\frac{R_2}{R_1}\right) = \left(\frac{R_2}{R_1}\right) \tag{3}$$
$$\rightarrow R_1R_4 = R_2R_3.$$

Then, from (2)

$$V_o = \left(\frac{R_2}{R_1}\right)(V_2 - V_1) \tag{4}$$

Let

$$R_1 = R_3 = R, \;\; R_2 = R_4 = KR \tag{5}$$

then the condition in (3) will be satisfied. The circuit acts as FGDA of GC *K*. Note that the GC can be adjusted by varying two resistors R_2 and R_4. However, it has finite input resistances at both the input terminals, and buffer(s) will be required preceding this circuit.

Case B: $V_1 = V_2 = V_i$

Under this condition Fig. 1 reduces to a single input circuit shown in Fig. 3. This configuration has appeared in several papers, for example [2]-[14].

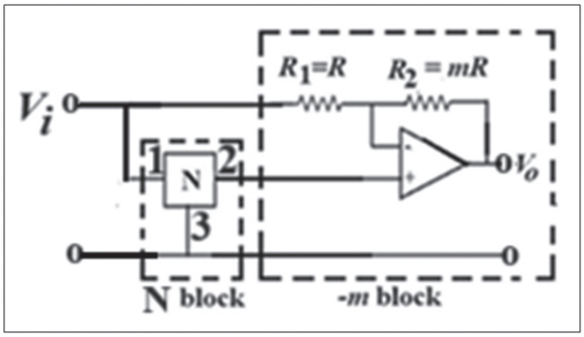


Figure 3. A single input circuit for case B.

Equation (1) gives

$$T_1(s) = \frac{V_o}{V_i} = [T_N(s)(1+m) - m] \tag{6}$$

This can also be written as

$$T_2(s) = [(-m)(1+T_N(s)] + T_N(s)] \tag{7}$$

Examination of (8) and (9) shows that (-*m*) and N blocks can be interchanged. Thus, the alternative circuit of Fig. 3 is shown in Fig. 4.

Although the two circuits of Figs. 3 and 4 have the same VTF, the latter one has a finite output impedance. Therefore, it will require a buffer when connected to some other circuit. We will not consider this circuit any more.

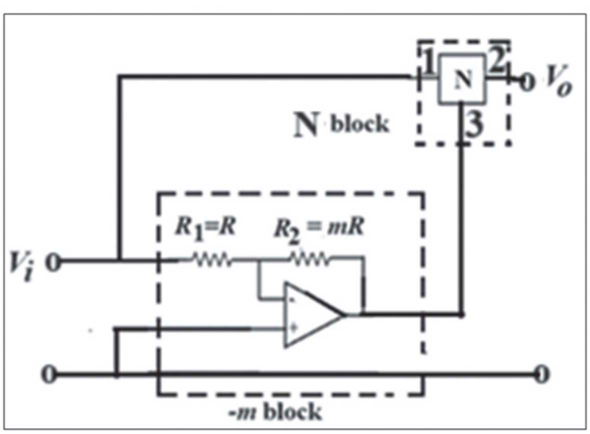


Figure 4. Alternative circuit.

If the input and ground terminals of N are interchanged (complementary transformation [15]-[18]), the transfer function becomes

$$\begin{aligned} T_3(s) &= [\{1 - T_N(s)\}(1+m') - m'] \\ &= -\frac{1}{m'}[\{1 - T_N(s)\}(1+m') - m'] \end{aligned} \tag{8}$$

Thus, the GC has become $-(1/m')$ where $m' = \frac{1}{m}$.

III. GC ADJUSTMENT FACILITY

Let us modify the circuit of Fig. 3 as shown in Fig. 5. The VTF of the modified circuit is

$$T_4 = T_N\left(\frac{R_a}{R_b} + \frac{R_a}{R_1} + 1\right) - \frac{R_a}{R_1} \tag{9}$$

Note that $T_{4|R_b \to \infty} = T_1$.

Let

$$T_M = KT_4 = K\left[T_N\left(\frac{R_2}{R_1} + 1\right) - \frac{R_2}{R_1}\right] \tag{10}$$

Comparing (9) and (10), we get

$$\frac{R_a}{R_1} = K\frac{R_2}{R_1} \to R_a = KR_2 \tag{11}$$

And

$$\begin{aligned} \left(\frac{R_a}{R_b} + \frac{R_a}{R_1} + 1\right) &= K\left(\frac{R_2}{R_1} + 1\right) \\ \to R_b &= \left(\frac{K}{K-1}\right)R_2 \end{aligned} \tag{12}$$

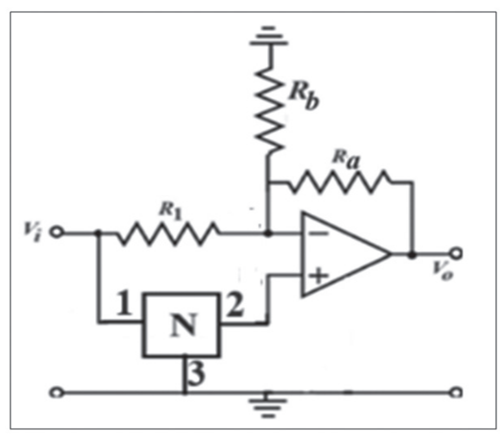


Figure 5. Circuit with GC adjustment facility.

Thus, the GC has become *K* times larger than that of the circuit of Fig. 3. Note that R_a and R_b values are independent of any of the parameters of N. Thus, the technique is applicable to any N. The circuit with $R_b = \infty$ (when $K = 1$), will be termed as *basic circuit.*

Demonstration of the technique

A) Difference Amplifier

Let GC of the conventional difference amplifier of Fig. 2 be *K*. Then the total resistance is

$$R_C = (2 + 2K)R. \quad (13)$$

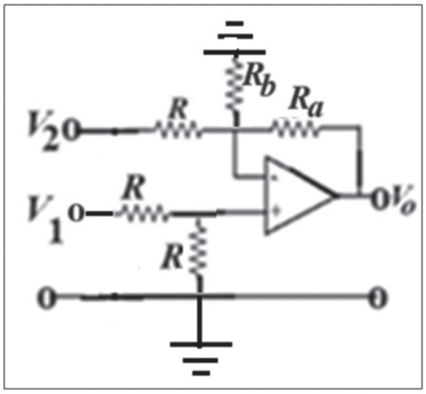


Figure 6. Modified difference amplifier

The modified difference amplifier is shown in Fig. 6. The total resistance is

$$R_M = 3R+KR+KR/(K\text{-}1). \quad (14)$$

$R_M \leq R_C$ when

$$3R+KR+KR/(K\text{-}1)\leq(2+2K)R \quad (15)$$

$\rightarrow K^2\text{-}3K+1$

i.e., when $1 \leq K \leq 2.6$. Let the desired K be 3. Then $R_a = 3R$, $R_b = (3/2)R$. $R_C = 8R$, $R_M = 7.5R$.

B) <u>Active Bridge</u>

VTF of the active bridge circuit [20] shown in Fig. 7 is

$$T(s) = \frac{R_1R_4 - R_2R_3}{R_1(R_3 + R_4)}. \quad (16)$$

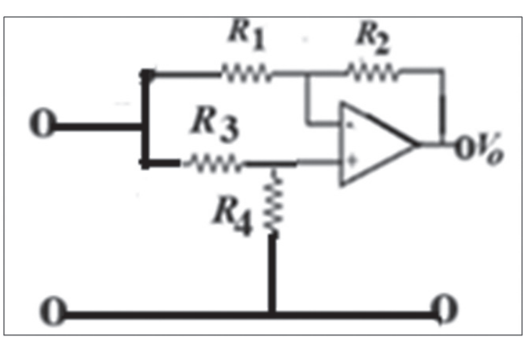


Figure 7. An active bridge.

The output voltage will be zero when

$$R_1R_4 - R_2R_3 = 0. \quad (17)$$

This is the well-known null condition for a conventional Wheatstone bridge [21]. However, the active bridge has the following features.

(i) It has a common ground between the input and output.

(ii) It has zero output resistance and therefore can be loaded at the output without any buffer.

Now if we modify the circuit as shown in Fig. 8, the transfer function becomes

$$T(s) = K\left(\frac{R_1R_4 - R_2R_3}{R_1(R_3 + R_4)}\right). \quad (18)$$

Thus, the output voltage becomes K times larger. Hence, we will be able to detect the null point more accurately in the presence of noise. While we require an instrumentation amplifier to enhance the output voltage of the Wheatstone Bridge.

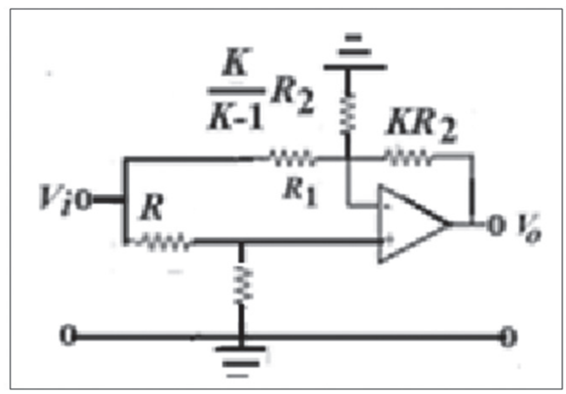


Figure 8. Modified active bridge.

C) <u>First order all-pass filter</u>

Let us consider the first order all-pass circuit shown in Fig. 9.

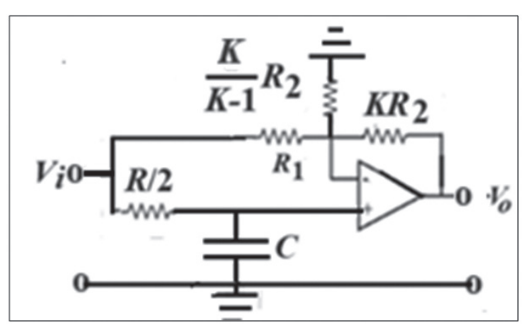


Figure 9. First order all-pass filter.

Thus, the GC has become K times of that of the basic circuit. For a GC of 4, $R_a = 4R_1$, $R_b = (4/3)\ R_1$. can be realized by 4 resistors of value R in series and can be realized by one resistor R in series with 3 resistors of value R in parallel. Also, $R/2$ can be realized by two resistors of value R in parallel Thus, the total number of resistors required is $N_R = 11$each of values R.

Total resistance is

$$R_T = \frac{R}{2} + R_1 + R_2 + R_3 \; = \frac{R}{2} + R + 4R + \left(\frac{4}{3}\right) R \cong 7R.$$

Whereas the circuit of [1] using FGDA of Fig. 2, both N_R and R_T equal 14R, in addition to two buffers when the GC of the difference amplifier A is 4.

The relation for GC given by (11) of [1] is in error. The correct values is

$$G = \frac{1}{\frac{1}{A} + 3} \tag{20}$$

Thus, K can be varied between ¼ and 1/3 when A is 1 and ∞, respectively. For the latter value of K, GC is fixed at 1/3 (not 3) and cannot be varied. Also, in [19], (when $R_1 = R_2 = R$ and $R_3 = R/2$, so that it gives the same transfer function as given by (19), the GC is fixed at 1 and cannot be varied. Thus, from the fabrication point in discrete or integrated forms, proposed circuit is better.

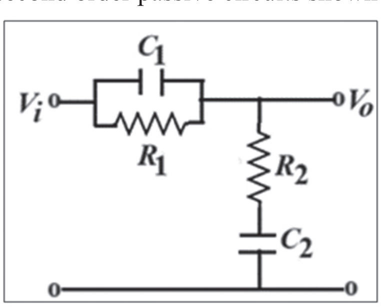
It is not fare for the author of [1] to compare the circuit of Fig. 6 with that of [19] as they are having different VTFs.

If the input and ground terminals of the basic circuit of Fig. 7 (K = 1) are interchanged, we get the complementary network that has VTF [17]-[20]

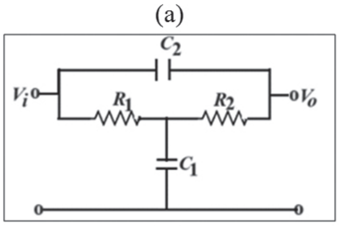
$$T_9(s) \;= 1 - T_5(s) = \frac{2sCR}{2 + sCR} \tag{21}$$

D) <u>Second order all pass filters</u>

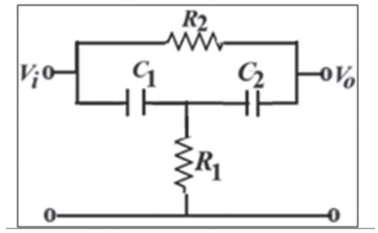
Consider the second order passive circuits shown in Fig. 10.



(a)



(b)



(c)

Figure 10. Circuits for N for case D.

These circuits have the same transfer function (with $R_1 = R_2 = R$ and $C_1 = C_2 = C$)

$$T_6(s) = \frac{s^2 + \left(\frac{2}{CR}\right) s + \frac{1}{C^2R^2}}{s^2 + \left(\frac{3}{CR}\right) s + \frac{1}{C^2R^2}}. \tag{22}$$

Then the overall transfer function becomes

$$T_7(s) = K\left\{\frac{s^2 + s\left[\frac{2-m}{CR}\right] s + \frac{1}{C^2R^2}}{s^2 + \left[\frac{3}{CR}\right] s + \frac{1}{C^2R^2}}\right\} \tag{23}$$

Then, the GC has become K times larger than that of the basic circuit. This is a band reject filter (BRF) when m = 2 and all-pass filter when m = 5.

If we interchange the input and ground terminals of N, the new transfer function will be [17] - [20]

$$T_8(s) = \frac{V_o}{V_i} = [\{1 - T_N(s)\}(1 + m) - m]$$
$$= -K\left\{\frac{\left[\frac{2-m}{CR}\right]\left[\frac{1}{CR}\right] s}{s^2 + \left[\frac{3}{CR}\right] s + \frac{1}{C^2R^2}}\right\}. \tag{24}$$

It is an APF filter when m = 5 and BRF when m = 2.

If the input and ground terminals of the basic circuit in Fig. 3 with K = 1 and N is any of the circuits of Fig. 7, are interchanged, we get the complementary VTF [15]- [18]

$$T_9(s) = 1 - \left\{\frac{s^2 + s\left[\frac{2-m}{CR}\right] s + \frac{1}{C^2R^2}}{s^2 + \left[\frac{3}{CR}\right] s + \frac{1}{C^2R^2}}\right\}. \tag{25}$$

IV. CIRCUITS WITH OTHER DEVICES

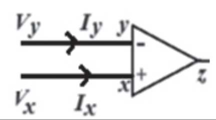
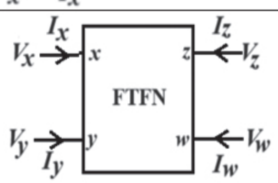
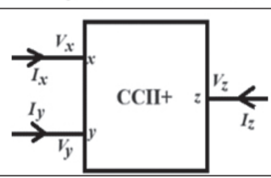
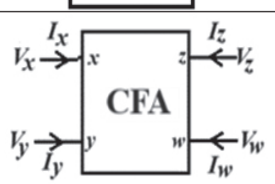
In sections 2 and 3, we have used the following terminal characteristics of the OA given in Table 1.

$$V_x = V_y \tag{26}$$

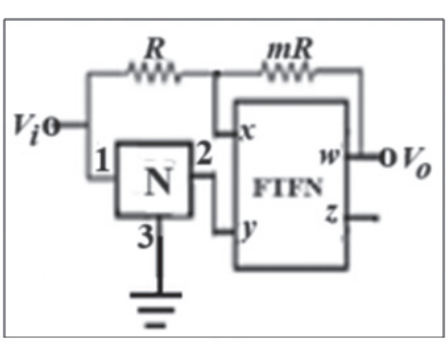
and

$$I_x = I_y = 0. \tag{27}$$

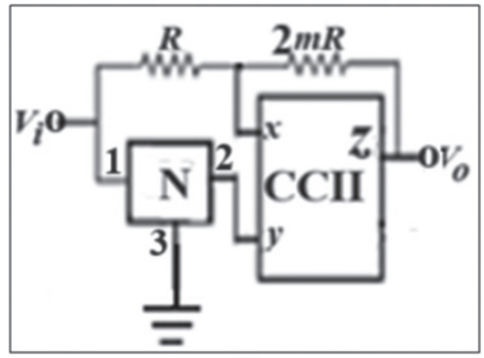
TABLE 1 -- VARIOUS DEVICES, THEIR SYMBOLS AND CHARACTERISTICS

Device	*Symbol*	*Terminal characteristics*
OA		$V_x = V_y$, $I_x = I_y = 0$
FTFN		$V_x = V_y$, $I_x = I_y = 0$, $I_z = \pm I_w$.
CCII		$V_x = V_y$, $I_y = 0$, $I_z = I_x$.
CFA		$V_x = V_y$, $I_x = I_z$, $I_y = 0$, $V_z = V_w$

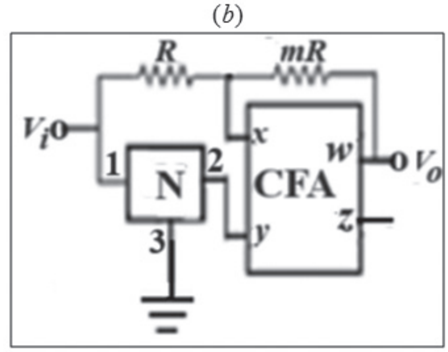
The OA in Fig. 1 is replaced by other active devices as shown in Fig 12. In Fig. 11(a), FTFN satisfy (26) and (27). Therefore, OA can directly be replaced by FTFN. Output is taken at z terminal which follows the voltage of w terminal, but offers zero output impedance. In Fig. 11(b), CCII satisfies (26), but does not (27). The current at x terminal is not 0 but equal to I_z, the current through the feedback resistance is halved. Hence, to give the same output voltage, the feedback resistance is doubled. In Fig. 11(c), CFA satisfies (26) and $I_y = 0$, but $I_x \neq 0$. To force $I_x = 0$, I_z is made 0 by keeping the z terminal open.



(a)



(*b*)



(*c*)

Figure 11. Circuits with other devices.

Circuits of Figs. 11(a) and (b) have appeared in [22]-[23].

V. CONCLUSION

Starting from a general dual input active circuit, we have obtained a difference amplifier and a single input circuit. We have introduced the gain constant adjustment facility by adding one resistor. The technique is demonstrated with difference amplifier, an active bridge, and first and second order all pass filters. It is pointed out that relation for GC of Dutta Roy is not correct. Therefore, all his claims are not true based on this relation. The proposed filters are better suited for fabrication both in discrete and integrated forms.

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