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Band Reject and Band Pass Filters from All-Pass Filters

Tejmal Rathore
Independent Researcher,
G-803, Country Park, Dattapada Road, Borivali (E), Mumbai 400066, India

ABSTRACT - A simple way of obtaining the band reject filter and band pass filter from an all-pass filter has appeared recently. But the implementation suggested requires too many components. Alternate simple circuit is suggested which requires small number of components, and can be cascaded without any buffer.

Key Words - *All pass filter, band pass filter, band reject filter, complementary transformation*

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I. INTRODUCTION

Recently Dutta Roy (2024) has suggested how to get band reject filter (BRF) and band pass filter (BPF) from an all-pass filter (APF). This is schematically shown in Figure 1. This is modified version of Figure 1 of Dutta Roy (2024). The (-1) block is removed and proper polarities are marked to the two summers. Note that it works only when the APF has value 1 at 0 and infinite frequencies, i.e., when

$$T_{AP} = \frac{s^2 - as + b}{s^2 + as + b} \tag{1}$$

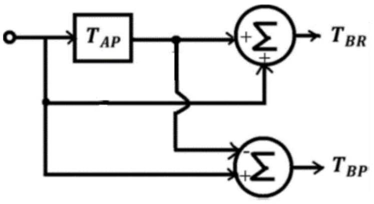


Figure 1: Schematic implementation of the BRF and BPF.

For implementation of BPF, Dutta Roy (2024) suggested the circuit shown in Figure 2.

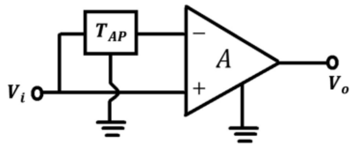


Figure 2: Circuit for BPF.

He has chosen an APF shown in Figure 3 which has $b = 1$. Because of the finite output impedance, it will get loaded by the summer and difference blocks. Conventional summer and the difference blocks using OAs are shown in Figures 3(a) and (b), respectively. Because of the finite input impedances at both the inputs, they will load the APF if the latter does not have a buffer. Note that the summer block will give negative output.

If A is ∞, the amplifier will be in open circuit mode and will not work. Thus, too many components are needed. An alternative single operational amplifier (OA) APF is suggested which requires a smaller number of components and can be cascaded, and no more addition or subtraction. We have derived the all-pass filters using other active devices such as CFA, FTFN, CCII, OTRA. We have extended the method to current mode filters.

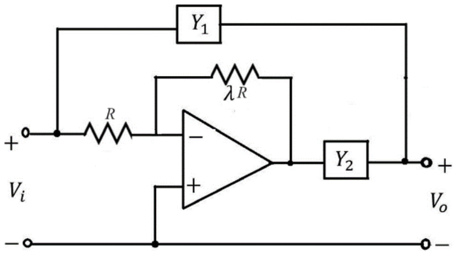


Figure 3: APF.

II. ALTERNATIVE ALL-PASS FILTERS

Then BRF and BPF functions are obtained as

$$T_{BR} = 1 + T_{AP} = \frac{2(s^2 + b)}{s^2 + as + b} \tag{2}$$

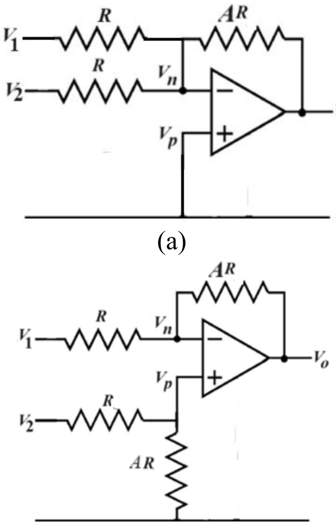
and

$$T_{BP} = 1 - T_{AP} = \frac{2as}{s^2 + as + b}. \tag{3}$$

As mentioned above, schematic of Figure 1 works only when T_{AP} block does not get loaded by the summers. Therefore, the choice of the circuit for T_{AP} Dutta Roy (2024) shown in Figure 2 is not a good one. Because it has finite output impedance, it can only be used with a buffer. Thus, this circuit becomes 2 OA circuit. We suggest the single OA circuit as shown in Figure 5 for the APF, where N can be any of the 3-terminal RC networks shown in Figure 6 (Rathore 1980). All these networks have the same voltage transfer function (VTF) (choosing $R_1 = R_2 = R$ and $C_1 = C_2 = C$ for convenience)

$$T(s) = \frac{s^2 + \left(\frac{2}{CR}\right)s + \frac{1}{C^2R^2}}{s^2 + \left(\frac{3}{CR}\right)s + \frac{1}{C^2R^2}}. \tag{4}$$

VTF of the circuit of Figure 5 can be obtained as



(a)

(b)

Figure 4: Conventional (a) Summing amplifier (b) Difference amplifier

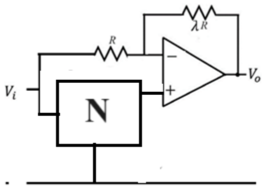
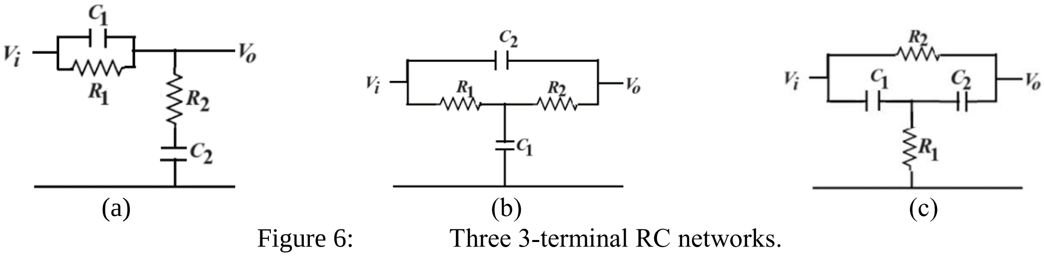


Figure 5: A single OA APF.



(a) (b) (c)

Figure 6: Three 3-terminal RC networks.

(5)

$$T(s) = \frac{s^2 + \left(\frac{2-\lambda}{CR}\right)s + \frac{1}{C^2R^2}}{s^2 + \left(\frac{3}{CR}\right)s + \frac{1}{C^2R^2}}.$$

Thus, it is an all pass when λ = 5. It is interesting to note that it also acts as a BR filter when λ = 2. It has ideally a zero-output impedance and acts as both APF and BRF without any additional summers; just by changing one resistor.

If the input and ground terminals of N in Fig. 3 are interchanged, the circuit becomes as shown in Fig. 5. The VTF of the circuit is given by (Rathore, 1980), (Rathore *et al.*1980).

$$T'(s) = (1 - T)(1+\lambda') - \lambda' = -\lambda' \left[\frac{s^2 + \left(\frac{2 - 1/\lambda'}{CR}\right)s + \frac{1}{C^2R^2}}{s^2 + \left(\frac{3}{CR}\right)s + \frac{1}{C^2R^2}}\right]. \tag{6}$$

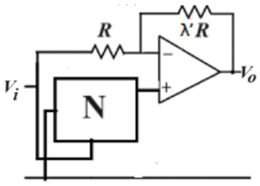


Figure 7: Modified circuit.

This will be an APF when λ' = 1/5 and BRF when λ' = ½. However, this $T'(s)$ will not give the BRF and BPF as $T(s)$ of Equation (3), because the gain constant is λ' and not 1.

Dutta Roy's circuit (2024) for BRF using an OA is shown in Figure 7. We find that R_2 in Figure 6 is redundant and can be eliminated. Then the circuit becomes as shown in Figure 8.

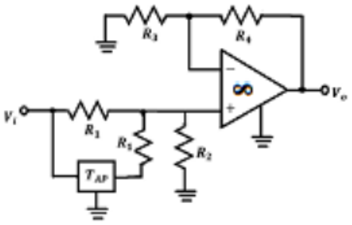


Figure 8: Circuit implementation of the BRF.

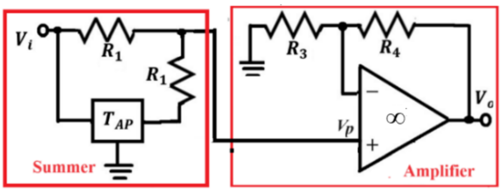


Figure 9: Circuit after removing R_2.

Assuming that T_{AP} block is followed by a buffer (to avoid loading by R_1's), the voltage at the non-inverting terminal is

$$V_p = \frac{1}{2}(1 + T_{AP}). \tag{7}$$

Thus, the BR output is available as the V_p itself with a gain of ½. This is amplified by, since OA is configured as a non-inverting amplifier, a factor (1+ R_4/R_3). Thus,

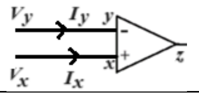
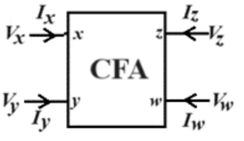
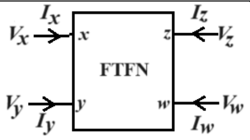
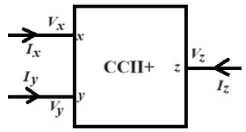
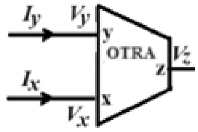
$$V_o = \left(\frac{R_3 + R_4}{2R_3}\right)(1 + T_{AP}). \tag{8}$$

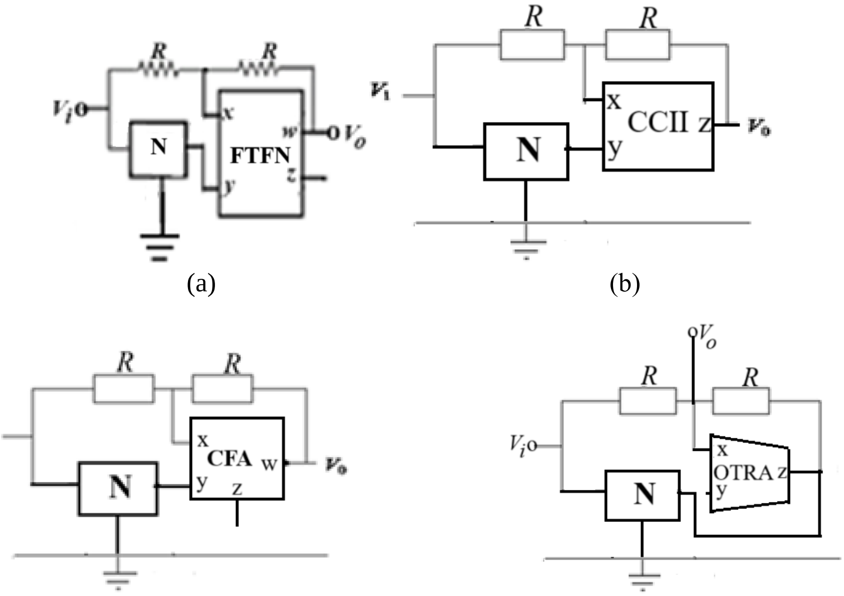
Now can be adjusted by a single resistance R_4. Thus, for a gain of 1, $R_4 = R_3$ and for a gain of 2, $R_4 = 3R_3$.

It is suggested by Dutta Roy (2024) that the resistances R_1-R_4 can be chosen to adjust the gain to the desired level. If R_1 is involved in the process, then two R_1 resistances have to be varied simultaneously which is not preferred in practice. Thus, either R_3 or R_4 should be varied to adjust the gain.

Dutta Roy (2024) has plotted the frequency responses from the equations which are standard ones differing by a scaling factor of 2. If the circuits were simulated, the effect of ignoring the loading would have appeared. In our case, we have not made any such assumption regarding the loading. Hence, we will get the same frequency response both from the simulations of the circuits as well as equations.

Table 1. Various devices, symbols and characteristics

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



(c) (d)

Figure 10: Realization of voltage transfer functions using (a) OTRA, (b) CCII, (c) CFA (d) FTFN

III. USING OTHER DEVICES

In previous section, we have used the following terminal characteristics of the OA given in Table 1.

$$V_x = V_y, \tag{9}$$

$$I_x = I_y = 0. \qquad (10)$$

The OA in Figure 5 is replaced by other active devices as shown in Figure 10. In Figure 10(a), FTFN satisfy both the conditions (9) and (10). Therefore, OA can directly be replaced by these devices. The output is taken at z terminal which follows the voltage of w terminal, but offers zero output impedance. In Figure 10(b), CCII satisfies Equation (9), but does not Equation (10). 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 Figures 10(c) and (d) CFA satisfies Equation (9) 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. In Figure 10(d), OTRA satisfies Equation 9, but not (10). The latter one is satisfied by keeping the terminal x open so that both I_x and I_y are 0.

Detailed design of the circuits of Figure 10 have appeared in Rathore *et al.* 2005, Rathore *et al*. 1975, Khot (2010), Rathore *et al.* 2008.

IV. CONCLUSION

A BRF and BPF can be derived from an APF which has value 1 at both 0 and ∞ frequencies and has zero output resistance so that it can be cascaded. The choice of Dutta Roy (2024) for APF does not fulfil the last condition. It requires a buffer. An alternative APF using a single OA is given which requires a smaller number of components, and can be cascaded. This can be converted into BRF and BPF without any additional components.

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