A universal active R filter

Active R filters use only resistors and op amps to realise the common transfer functions. *Ahmed M Soliman* and *Mahmoud Fawzy* of Cairo University describe a new active R filter.

Recently, there has been a great interest in the new class of filters, termed active R filter (1-3), which are based upon the one pole model of the operational amplifier.

In this paper, a new active R filter is given. The network realizes inverting bandpass and lowpass transfer characteristics of any arbitrary gain at two different output terminals. At a third output terminal, a general biquadratic transfer characteristics is obtained, namely, a non-minimum phase, a generalized notch or a highpass transfer function.

Design equations for each class of filters are given. Sensitivities to all active and passive circuit parameters are shown to be very low.

The network

For the circuit of Fig. 1, assuming,

$$A_i = \frac{GB_i}{s} \quad (i = 1,2,3) \qquad \text{.............(1)}$$

as proposed in reference (2), where GB is the gain bandwidth product of the operational amplifier, the transfer functions at different output terminals can be calculated. By direct analysis, it is seen that:

$$T_1(S) = \frac{V_2}{V_1} = K\frac{s^2 - s\left(\frac{\omega_z}{Q_z}\right) + \omega_z^2}{s^2 + s\left(\frac{\omega_p}{Q_p}\right) + \omega_p^2} \qquad (2)$$

where:

$K = a/b$ ....(3)

$a = R_2/R_1$ ....(4)

$b = 1 + a + R_2/R_3$ ....(5)

$\omega_z^2 = m.n.\ GB_1 . GB_2/a$ ....(6)

$\omega_p^2 = m.\ GB_1 . GB_2/b$ ....(7)

$Q_z = \omega_z . a/(p.GB_2)$

$= \frac{1}{p} . \sqrt{m.n.\ a\ GB_1/GB_2}$ ....(8)

$Q_p = \omega_p . b/[GB_3 . (b-a-1)]$

$= \frac{\sqrt{m.\ b.\ GB_1 . GB_2}}{(b-a-1) . GB_3}$ ....(9)

$n = R_5/(R_4+R_5)$ ....(10)

$m = R_7/(R_6+R_7)$......................(11)

$p = R_9/(R_8+R_9)$ ....(12)

From the above equations, it is seen that an all-pass, a generalized notch and a highpass response can be obtained as follows:—

Case 1: All-pass transfer function

Equation (2) represents an all-pass characteristics if:

$n = K$ (i.e. $\frac{R_5}{R_4} = \frac{R_2//R_3}{R1}$) ....(13)

$p = \frac{GB_3}{GB_2} . \frac{a(b-a-1)}{b}$

(i.e. $\frac{R_9}{R_8+R_9} = K . \frac{GB_3 . R_2}{GB_2\ R_3}$) ......(14)

Case 2: Generalized notch filter

Equation (2) represents a generalized notch filter if:

$p = 0$ (i.e. $R_9 = 0$, $R_8 = \infty$) ....(15)

All types of notch transfer characteristics can be obtained depending on the value of n:

(i) $n = K$ (notch filter) ....(16)

(ii) $n > K$ (lowpass notch) ....(17)

(iii) $n < K$ (highpass notch) ....(18)

Case 3: Highpass filter

Equation (2) represents a highpass filter if:

$p = 0$ ....(19)

$n = 0$ (i.e. $R_5 = 0$, $R_4 = \infty$).........(20)

Design equations

For equation (2), given f_p, Q_p, f_z, Q_z and K, the design equations are:—

$\frac{R_3}{R_2} = D(1-K) - 1$ ....(21)

$\frac{R_1}{R_2} = \frac{1}{K}\left(1 - K - \frac{1}{D}\right)$ ....(22)

$\frac{R_6}{R_7} = \frac{f_{c1} . f_{c2}}{f^2_p} . \left(1 - K - \frac{1}{D}\right) - 1$ ...(23)

$\frac{R_4}{R_5} = \frac{1}{K}\left[\frac{f_p}{f_z}\right]^2 - 1$ ....(24)

$\frac{R_8}{R_9} = \frac{f_{c2}}{f_z} . \frac{Q_z}{K} . \left(1 - K - \frac{1}{D}\right) - 1$...(25)

where:

$D = Q_p . \frac{f_{c3}}{f_p}$ ....(26)

$f_{ci} = \frac{GB}{2\pi}$ (i = 1,2,3) ....(27)

Bandpass filter

When $\frac{V_2}{V_1}$ represents a highpass filter (i.e. $p = 0$, $n = 0$), then:

$$T_2(S) = V_3/V_1 = \frac{-H_1 . S}{s^2 + s\left(\frac{\omega_p}{Q_p}\right) + \omega_p^2} \qquad (28)$$

which represents a bandpass filter, where:

$H_1 = K . GB_3$ ....(29)

The midband gain is given by:

$|G_0| = \frac{a}{b-a-1} = \frac{R_3}{R_1}$ ....(30)

which can take any arbitrary value.

Bandpass equations

For a bandpass filter, given f_p, Q_p and $|G_0|$, the design equations are:—

$\frac{R_3}{R_1} = |G_0|$ ....(31)

$\frac{R_1}{R_2} = \frac{D-1}{|G_0|} - 1$ ....(32)

$\frac{R_6}{R_7} = \frac{f_{c1} . f_{c2}}{f^2_p} . \left(1 - \frac{1 + |G_0|}{D}\right) - 1$ ...(33)

When $\frac{|V_2|}{|V_1|}$ represents a highpass filter (i.e. $p = 0$, $n = 0$), then:

$$T_3(s) = \frac{V_4}{V_1} = \frac{-H_2}{s^2 + s\left(\frac{\omega_p}{Q_p}\right) + \omega_p^2} \qquad (34)$$

which represents a lowpass filter, where:

$H_2 = m.\ K.\ GB_1 . GB_2$ ....(35)

The lowpass gain is given by:

$|G_0| = a = \frac{R_2}{R_1}$ ....(36)

which can take any arbitrary value.

Lowpass equations

For a lowpass filter given f_p, Q_p and $|G_0|$, the design equations are:

$\frac{R_2}{R_1} = |G_0|$ ....(37)

$\frac{R_2}{R_3} = \frac{1 + |G_0|}{D-1}$ ....(38)

$\frac{R_6}{R_7} = \frac{f_{c1} . f_{c2}}{f^2_p} . \left[\frac{1 - 1/D}{1 + |G_0|}\right] - 1$......(39)

x	R1	R2	R3	R4	R5	R6	R7	R8	R9	GB1	GB2	GB3
S_x^{wP}	$\frac{1}{2} . \frac{a}{b}$	$-\frac{1}{2} . \frac{b-1}{b}$	$\frac{1}{2} . \frac{b-a-1}{b}$	0	0	$-\frac{1}{2}(1-m)$	$\frac{1}{2}(1-m)$	0	0	$\frac{1}{2}$	$\frac{1}{2}$	0
S_x^{QP}	$-\frac{1}{2} . \frac{a}{b}$	$-\frac{1}{2} . \frac{b+1}{b}$	$\frac{1}{2} . \frac{b+a+1}{b}$	0	0	$-\frac{1}{2}(1-m)$	$\frac{1}{2}(1-m)$	0	0	$\frac{1}{2}$	$\frac{1}{2}$	-1
S_x^{wz}	$\frac{1}{2}$	$-\frac{1}{2}$	0	$-\frac{1}{2}(1-n)$	$\frac{1}{2}(1-n)$	$-\frac{1}{2}(1-m)$	$\frac{1}{2}(1-m)$	0	0	$\frac{1}{2}$	$\frac{1}{2}$	0
S_x^{Qz}	$-\frac{1}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}(1-n)$	$\frac{1}{2}(1-n)$	$-\frac{1}{2}(1-m)$	$\frac{1}{2}(1-m)$	$1-p$	$-(1-p)$	$\frac{1}{2}$	$-\frac{1}{2}$	0

Fig. 1 shows the circuit of the universal active R filter. The circuit realises inverting bandpass, lowpass and general biquadratic transfer functions.

Sensitivities

The table summarizes the sensitivities of ω_p, Q_p, ω_z, Q_z with respect to all elements of the circuit. It is apparent that $|S^{\omega}_x| < 0{,}5$; $|S^{Q}_x| < 1$ where x stands for any active or passive circuit element, which implies very small sensitivities. □

References

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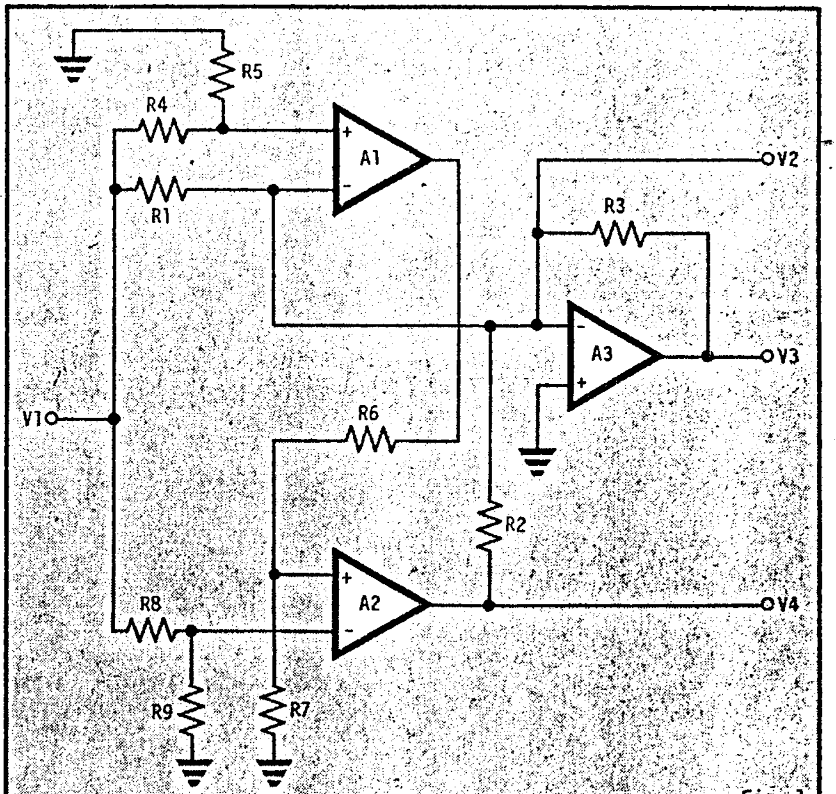

Fig. 1