E4215: Analog Filter Synthesis and Design
Transfer functions realizable in a biquad

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1 opamp-RC filter

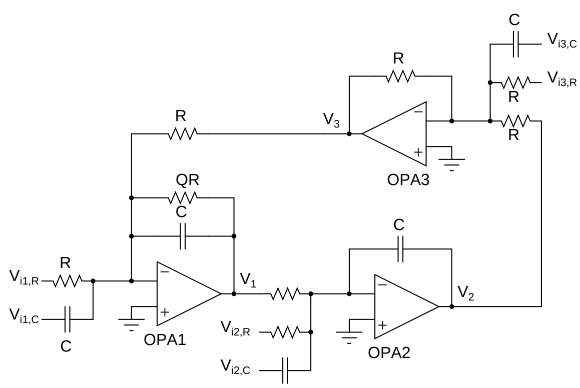

Figure 1: Tow-Thomas biquad with various possible inputs

Table 1: Transfer function between different inputs and outputs in Fig. 1. $D(s) = 1 + \frac{sCR}{Q} + (sCR)^2$

	V_1	V_2	V_3
$V_{i1,R}$	$-\frac{sCR}{D(s)}$	$\frac{1}{D(s)}$	$-\frac{1}{D(s)}$
$V_{i2,R}$	$-\frac{1}{D(s)}$	$-\frac{1/Q + sCR}{D(s)}$	$\frac{1/Q + sCR}{D(s)}$
$V_{i3,R}$	$\frac{sCR}{D(s)}$	$-\frac{1}{D(s)}$	$-\frac{sCR/Q + (sCR)^2}{D(s)}$
$V_{i1,C}$	$-\frac{(sCR)^2}{D(s)}$	$\frac{sCR}{D(s)}$	$-\frac{sCR}{D(s)}$
$V_{i2,C}$	$-\frac{sCR}{D(s)}$	$-\frac{sCR/Q + (sCR)^2}{D(s)}$	$\frac{sCR/Q + (sCR)^2}{D(s)}$
$V_{i3,C}$	$\frac{(sCR)^2}{D(s)}$	$-\frac{sCR}{D(s)}$	$-\frac{(sCR)^2/Q + (sCR)^3}{D(s)}$

The last row in Table 1 using the capacitive input $V_{i3,C}$ is not practical because it introduces an extra pole in the feedback around opamp OPA3, degrading stability (as in an opamp differentiator). **Do not use this!**.

2 g_m-C filter

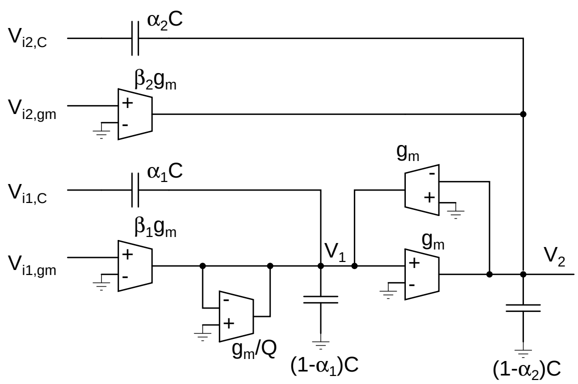

Figure 2: g_m-C filter with various possible inputs

Table 2: Transfer function between different inputs and outputs in Fig. 2. $D(s) = 1 + \frac{sC}{g_m Q} + \left(\frac{sC}{g_m}\right)^2$

	V_1	V_2
V_{i1,g_m}	$\beta_1 \frac{sC/g_m}{D(s)}$	$\beta_1 \frac{1}{D(s)}$
V_{i2,g_m}	$\beta_2 \frac{1}{D(s)}$	$\beta_2 \frac{1/Q + sC/g_m}{D(s)}$
$V_{i1,C}$	$\alpha_1 \frac{(sC/g_m)^2}{D(s)}$	$\alpha_1 \frac{sC/g_m}{D(s)}$
$V_{i2,C}$	$\alpha_2 \frac{sC/g_m}{D(s)}$	$\alpha_2 \frac{sC/Qg_m + (sC/g_m)^2}{D(s)}$

3 Realization of arbitrary numerator polynomials

Arbitrary numerator polynomials can be realized by

- Voltage summing: The input voltage is applied to one of the possible input terminals in Fig. 1 or Fig. 2. A summing circuit is used to generate a linear combination of the input voltage and the available outputs (V_{in}, V_1, V_2, V_3 in Fig. 1; V_{in}, V_1, V_2 in Fig. 2). The result is a row-wise weighted summation in Table 1 or Table 2.

- Feedforward: The output is taken from one of the output terminals (V_1, V_2, V_3 in Fig. 1; V_1, V_2 in Fig. 2). The input is applied to more than one input ($V_{ik,g_m}, V_{ik,C}$). The result is a column-wise weighted summation in Table 1 or Table 2.