Ouroboros 2164 Gain Cell Filter

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1 Introduction

Analysis of the Ouroboros filter. Heavily based on the Mutable Instruments Blades filter with influences from the Serge VCFQ as well. Much of this analysis is pulled from the SSM2164 SVF Analysis by Emilie Gillet and then just somewhat modified.

1.1 Notations

R_m is the value of the resistor at the input of the mixer section.

R_i is the value of the resistors in the input to the 2164 integrator cells.

R_{hp} is the value of the resistor through which the HP output is fed back into the input mixer.

R_{bp} is the value of the resistor through which the BP output is fed back into the input mixer.

R_{lp} is the value of the resistor through which the LP output is fed back into the input mixer.

R_q is the value of the resistor at the input of the gain cell feeding the BP output back to control the Q of the filter.

C is the value of the integrators' capacitors.

v_{cv} is the cutoff frequency control voltage.

v_q is the resonance control voltage.

v_i is the input voltage.

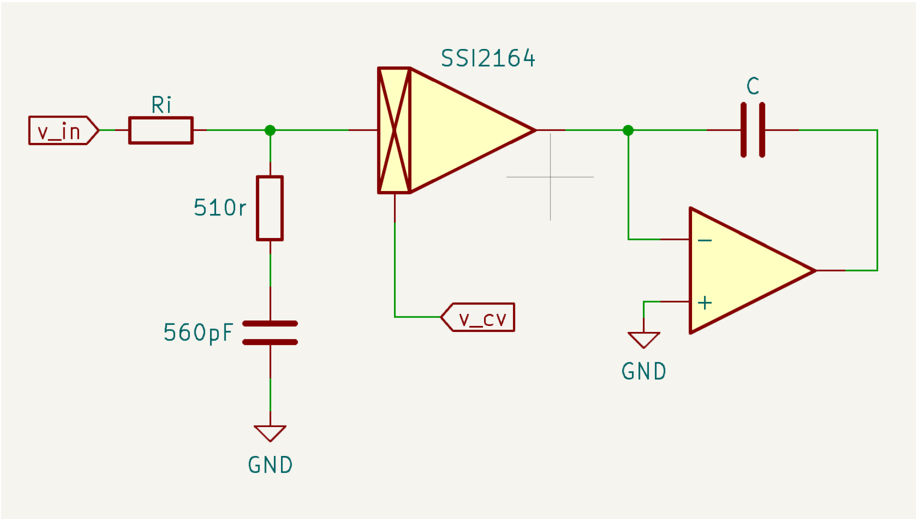
$v_{hp}(s)$, $v_{bp}(s)$ and $v_{lp}(s)$ are the high-pass, band-pass and low-pass output voltages.

For reference, the standard second-order filter transfer functions are:

$$H_{lp}(s) = \frac{1}{\tau^2 s^2 + \frac{1}{q}\tau s + 1}$$
$$H_{bp}(s) = \frac{1}{\frac{q}{\tau s} + q\tau s + 1}$$
$$H_{hp}(s) = \frac{1}{\frac{1}{\tau^2 s^2} + \frac{1}{q\tau s} + 1}$$

Where $\tau = \frac{1}{2\pi C}$

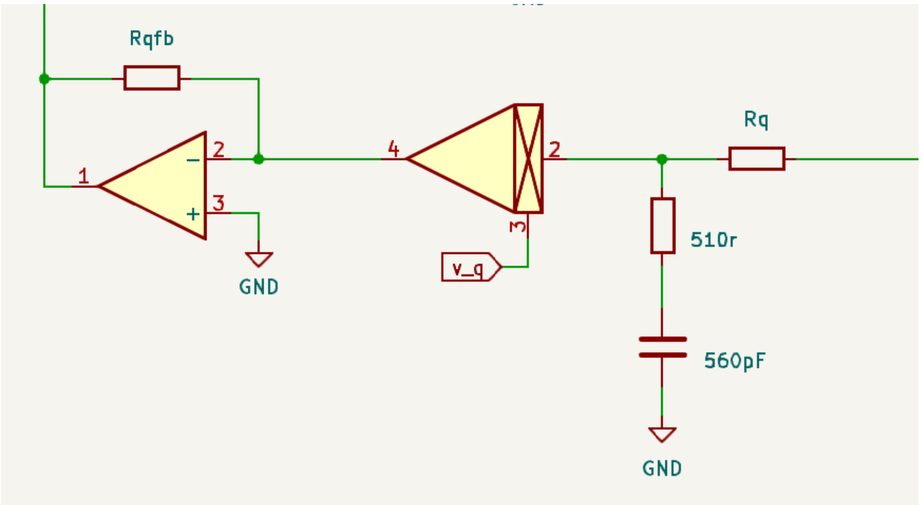
1.2 2164 Integrator Cell



The current gain of a 2164 gain cell is $i_{out} = i_{in} 10^{-\frac{3}{2} v_{cv}}$. The transfer function of the integrator cell α can then be calculated.

$$
\begin{aligned}
i_{in} &= \frac{v_{in}}{R_i} \\
i_{out} &= \frac{v_{in}}{R_i} 10^{-\frac{3}{2} v_{cv}} \\
v_{out} &= -\frac{i_{out}}{Cs} \\
v_{out} &= -\frac{\frac{v_{in}}{R_i} 10^{-\frac{3}{2} v_{cv}}}{Cs} \\
&= -\frac{v_{in} 10^{-\frac{3}{2} v_{cv}}}{CsR_i} \\
\alpha(s) &= \frac{v_{out}}{v_{in}} = -\frac{1}{CsR_i} 10^{-\frac{3}{2} v_{cv}}
\end{aligned}
$$

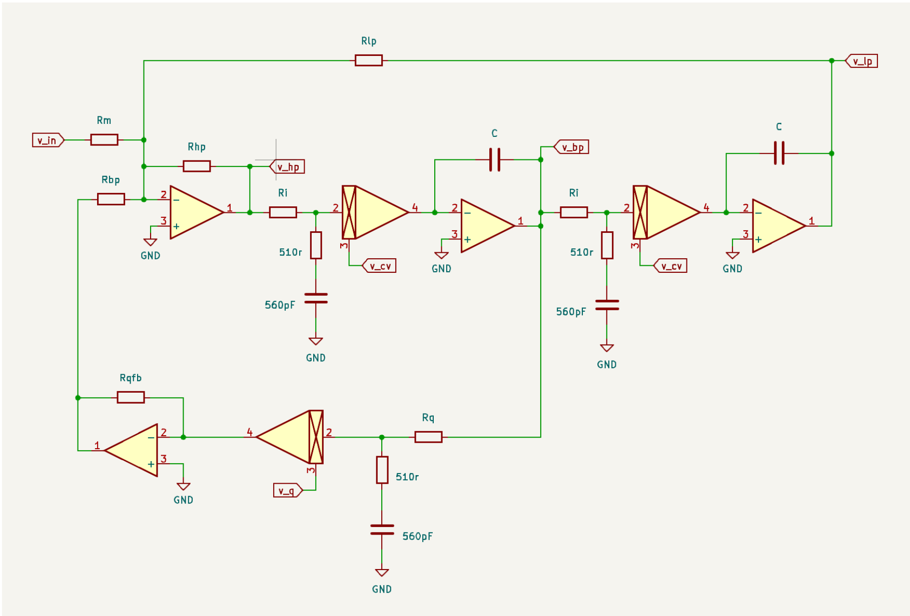
1.3 Resonance VCA



The transfer function of the resonance feedback VCA β can then be calculated.

$$
\begin{aligned}
i_{in} &= \frac{v_{in}}{R_q} \\
i_{out} &= \frac{v_{in}}{R_q} 10^{-\frac{3}{2}v_q} \\
v_{out} &= -i_{out} R_{qfb} \\
v_{out} &= -\frac{v_{in} R_{qfb}}{R_q} 10^{-\frac{3}{2}v_q} \\
\beta(s) &= \frac{v_{out}}{v_{in}} = -\frac{R_{qfb}}{R_q} 10^{-\frac{3}{2}v_q}
\end{aligned}
$$

1.4 Filter



$$\frac{v_i}{R_i} + \frac{v_{hp}}{R_{hp}} + \frac{v_{lp}}{R_{lp}} + \frac{v_{bp}}{R_{bp}} = 0$$

1.4.1 High-pass

$$
\begin{aligned}
\frac{v_{hp}(s)}{R_{hp}} &= -\frac{v_i(s)}{R_i} - \frac{\beta v_{bp}(s)}{R_{bp}} - \frac{v_{lp}(s)}{R_{lp}} \\
\frac{v_{hp}(s)}{R_{hp}} &= -\frac{v_i(s)}{R_i} - \frac{\beta\alpha(s)v_{hp}(s)}{R_{bp}} - \frac{\alpha^2(s)v_{hp}(s)}{R_{lp}} \\
\frac{v_i(s)}{R_i} &= -\frac{v_{hp}(s)}{R_{hp}} - \frac{\beta\alpha(s)v_{hp}(s)}{R_{bp}} - \frac{\alpha^2(s)v_{hp}(s)}{R_{lp}} \\
\frac{v_i(s)}{R_i} &= -v_{hp}(s)(\frac{1}{R_{hp}} + \frac{\beta\alpha(s)}{R_{bp}} + \frac{\alpha^2(s)}{R_{lp}}) \\
\frac{v_i(s)}{v_{hp}(s)} &= -R_i(\frac{1}{R_{hp}} + \frac{\beta\alpha(s)}{R_{bp}} + \frac{\alpha^2(s)}{R_{lp}}) \\
H_{hp}(s) &= \frac{v_{hp}(s)}{v_i(s)} = -\frac{1}{R_i}\frac{1}{(\frac{1}{R_{hp}} + \frac{\beta\alpha(s)}{R_{bp}} + \frac{\alpha^2(s)}{R_{lp}})} \\
R_{hp} &= R_{bp} = R_{lp} = R \\
&= -\frac{1}{R_i}\frac{1}{(\frac{1}{R} + \frac{\beta\alpha(s)}{R} + \frac{\alpha^2(s)}{R})} \\
&= -\frac{\frac{R}{R_i}}{1 + \beta\alpha(s) + \alpha^2(s)}
\end{aligned}
$$

$G = \frac{R}{R_i}$ is the pass-band gain.

1.4.2 Low-Pass

$$
\begin{aligned}
H_{lp}(s) &= \frac{v_{lp}(s)}{v_i(s)} \\
&= \frac{v_{hp}(s)}{v_i(s)}\alpha^2(s) \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{\alpha^2(s)} + \beta\frac{1}{\alpha(s)} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{\alpha^2(s)} + \beta\frac{1}{\alpha(s)} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{(-\frac{1}{CsR_i}10^{-\frac{3}{2}v_{cv}})^2} + (-\frac{R_{qfb}}{R_q}10^{-\frac{3}{2}v_q})\frac{1}{-\frac{1}{CsR_i}10^{-\frac{3}{2}v_{cv}}} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{(\frac{1}{CsR_i}10^{-\frac{3}{2}v_{cv}})^2} + (\frac{R_{qfb}}{R_q}10^{-\frac{3}{2}v_q})\frac{1}{\frac{1}{CsR_i}10^{-\frac{3}{2}v_{cv}}} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{(\frac{1}{s}\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}})^2} + (\frac{R_{qfb}}{R_q}10^{-\frac{3}{2}v_q})\frac{1}{\frac{1}{s}\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}}} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{1}{\frac{1}{s^2}(\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}})^2} + (\frac{R_{qfb}}{R_q}10^{-\frac{3}{2}v_q})\frac{1}{\frac{1}{s}\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}}} + 1} \\
&= -\frac{\frac{R}{R_i}}{\frac{s^2}{(\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}})^2} + (\frac{R_{qfb}}{R_q}10^{-\frac{3}{2}v_q})\frac{s}{\frac{1}{CR_i}10^{-\frac{3}{2}v_{cv}}} + 1}
\end{aligned}
$$

By comparing with the standard form of a second order filter transfer function we can work out the following.

Pass-band gain, $-\frac{R}{R_i}$

Cutoff frequency, $f = \frac{1}{2\pi R_i C}10^{-\frac{3}{2}v_{cv}}$

Quality factor, $\frac{R_q}{R_{qfb}}10^{\frac{3}{2}v_q}$

1.5 Calculating cutoff frequencies

Given the calculation for frequency, and picking some standard values we can calculate cutoff for different i_{cv} values.

R_i is 33k

C is 220pF

$$f = \frac{1}{2\pi * 33000 * 220 * 10^{-12}} 10^{-\frac{3}{2}v_{cv}} \tag{1}$$

for v_{cv} of 0V $f = 21922Hz$

for v_{cv} of 0.25V $f = 9244Hz$

for v_{cv} of 0.5V $f = 3898Hz$

for v_{cv} of 1V $f = 693Hz$

for v_{cv} of 2V $f = 21Hz$

for v_{cv} of 3V $f = 0.69Hz$

1.6 Calculating resonance

A quality factor of 1/2 gives no resonance, whilst the resonance (and likelihood of self oscillating) increases as Q goes to infinity.

Assuming that $\frac{R_q}{R_{qfb}} = 1/2$

R_q is 15k

R_{qfb} is 30k

$$q = \frac{15000}{30000} 10^{\frac{3}{2}v_q} \tag{2}$$

for v_q of 0.0V $q = 0.5$

for v_q of 0.25V $q = 1.18$

for v_q of 0.5V $q = 2.811$

for v_q of 1V $q = 15.8$

for v_q of 2V $q = 500$