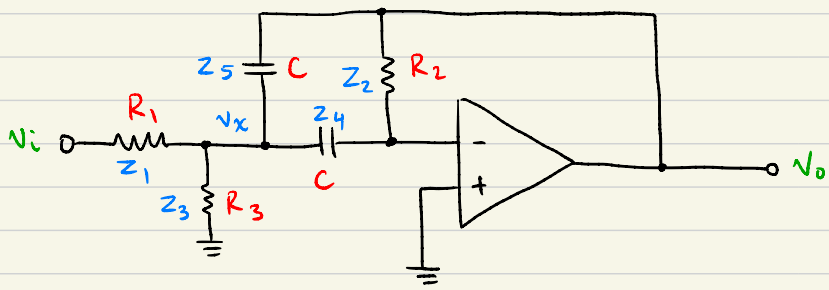
Graphic Equalizer

Kyle Pinto

Multiple Feedback Active Band Pass Filter



$Z_1 = R_1$
$Z_2 = R_2$
$Z_3 = R_3$

$Z_4 = Z_5 = \frac{1}{sC}$

$$\frac{V_x - V_i}{Z_1} + \frac{V_x}{Z_3} + \frac{V_x}{Z_4} + \frac{V_x - V_o}{Z_5} = 0$$

$$\frac{0 - V_x}{Z_4} + \frac{0 - V_o}{Z_2} = 0$$

$$V_x = -V_o \frac{Z_4}{Z_2}$$

$$V_x\left[\frac{1}{Z_1} + \frac{1}{Z_3} + \frac{1}{Z_4} + \frac{1}{Z_5}\right] - \frac{V_o}{Z_5} = \frac{V_i}{Z_1}$$

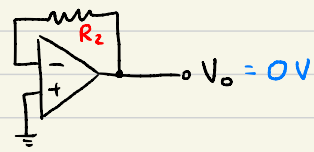
$$-V_o\left[\frac{Z_4}{Z_2}\right]\left[\frac{1}{Z_1} + \frac{1}{Z_3} + \frac{1}{Z_4} + \frac{1}{Z_5}\right] - \frac{V_o}{Z_5} = \frac{V_i}{Z_1}$$

$$-V_o\left[\frac{1}{sR_2C}\right]\left[\frac{1}{R_1} + \frac{1}{R_3} + sC + sC\right] - V_o sC = \frac{V_i}{R_1}$$

$$-V_o\left[\frac{1}{sR_2C}\right]\left[\frac{R_1 + R_3 + 2sR_1R_3C}{R_1R_3}\right] - V_o sC = \frac{V_i}{R_1}$$

$$-V_o\left[\frac{R_1 + R_3 + 2sR_1R_3C + s^2R_1R_2R_3C^2}{sR_1R_2R_3C}\right] = \frac{V_i}{R_1}$$

DC bias is removed by the two capacitors:



DC steady state

$$\boxed{H(s) = \frac{V_o}{V_i} = \frac{-sR_2R_3C}{R_1 + R_3 + 2sR_1R_3C + s^2R_1R_2R_3C^2}}$$

$$H(j\omega) = \frac{-j\omega R_2R_3C}{R_1 + R_3 + 2j\omega R_1R_3C - \omega^2R_1R_2R_3C^2}$$

$$|H(j\omega)|^2 = \frac{|-j\omega R_2R_3C|^2}{|(R_1 + R_3 - \omega^2R_1R_2R_3C^2) + 2j\omega R_1R_3C|^2}$$

$$= \frac{(\omega R_2R_3C)^2}{(R_1 + R_3 - \omega^2R_1R_2R_3C^2)^2 + (2\omega R_1R_3C)^2}$$

$$\boxed{|H(j\omega)| = \frac{\omega R_2R_3C}{\sqrt{(R_1 + R_3 - \omega^2R_1R_2R_3C^2)^2 + (2\omega R_1R_3C)^2}}, \quad \omega = 2\pi f}$$

$$\boxed{f_c = \frac{1}{2\pi C\sqrt{(R_1 \| R_3)R_2}}}$$

$$\boxed{A_c = \frac{-R_2}{2R_1}, \quad A_c < 2Q^2}$$

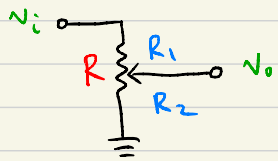
$$\boxed{R_2 = \frac{Q}{\pi f_c C}}$$

$$\boxed{Q = \frac{1}{2}\sqrt{\frac{R_2}{R_1 \| R_3}}}$$

$$\boxed{R_1 = \frac{Q}{2\pi f_c C A_c}}$$

$$\boxed{R_3 = \frac{Q}{2\pi f_c C(2Q^2 - A_c)}}$$

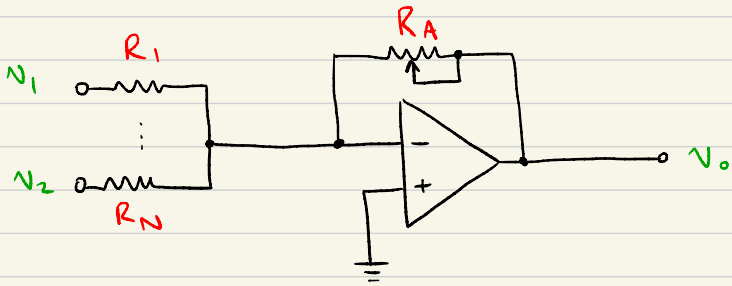
Fader



$$v_o = v_i \frac{R_1}{\underbrace{R_2}_{R-R_1}+R_1} = v_i \frac{R_1}{R}$$

The fader can only attenuate. At the highest setting, $v_o = v_i$, and at the lowest setting, $v_o = 0$. At the midpoint, $v_o = 0.5 v_i$ (assuming that the potentiometer is linear. Therefore, the filters should have an approximate A_c of 2 V/V, which will be 1 V/V at the centre of the fader.

Summing Amplifier



$$\frac{0-v_1}{R_1} + \dots + \frac{0-v_N}{R_N} + \frac{0-v_o}{R_A} = 0$$

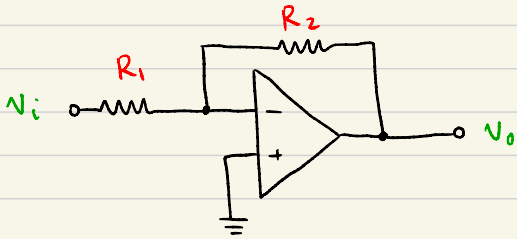
$$-\frac{v_1}{R_1} - \dots - \frac{v_N}{R_N} = \frac{v_o}{R_A}$$

If $R_1 = \dots = R_N = R$ then:

$$\boxed{v_o = -\frac{R_A}{R}\sum_{i=1}^{N} v_i}$$

Equally-weighted summation with maximum gain $A = \frac{R_A}{R}$

Inverting Amplifier

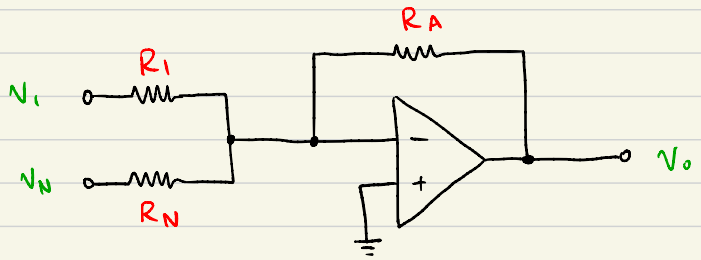


$$\frac{0-v_i}{R_1} + \frac{0-v_o}{R_2} = 0$$

$$\boxed{v_o = -\frac{R_2}{R_1} v_i}$$

This amplifier does not eliminate DC bias. But this filter is only for driving the inputs to the BPFs, so it will have unity gain. The BPFs will remove any DC bias.

Weighted Summing Amplifier



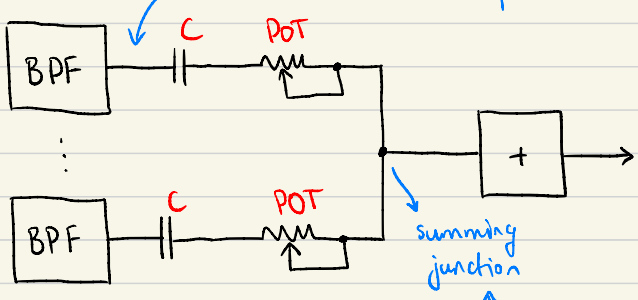
$$\boxed{V_o = -R_A\left[\frac{V_1}{R_1} + \dots + \frac{V_N}{R_N}\right]}$$

If $R_1, \dots, R_N$ are potentiometers, increasing R will decrease the volume of that band, and vice versa. R_A operates as an independent volume slider.

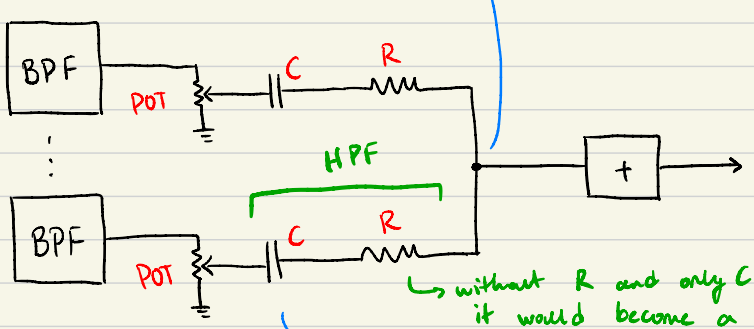
No R_2 will not mess it up. Cap is only for removing bias

$V_1, \dots, V_N$ must be directly connected to the output of the BPF to avoid messing up $R_1, \dots, R_N$. Even still, R_2 on the BPF may mess with $R_1, \dots, R_N$. R_2 is virtually connected to ground. So you may need a blocking capacitor between the BPF and the summing amplifier.

some examples put another resistor here, probably to draw current to the capacitor since the example uses DC biases.



works but the faders are non-linear



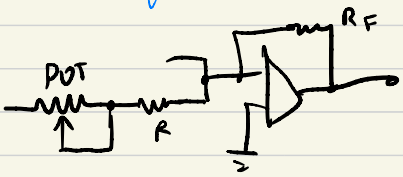
linear faders and the capacitor should isolate the input resistances of the summing amplifier.

without R and only C it would become a differentiator

removing these capacitors is basically the same as the weighted summer

Investigate linear vs logarithmic taper

B1



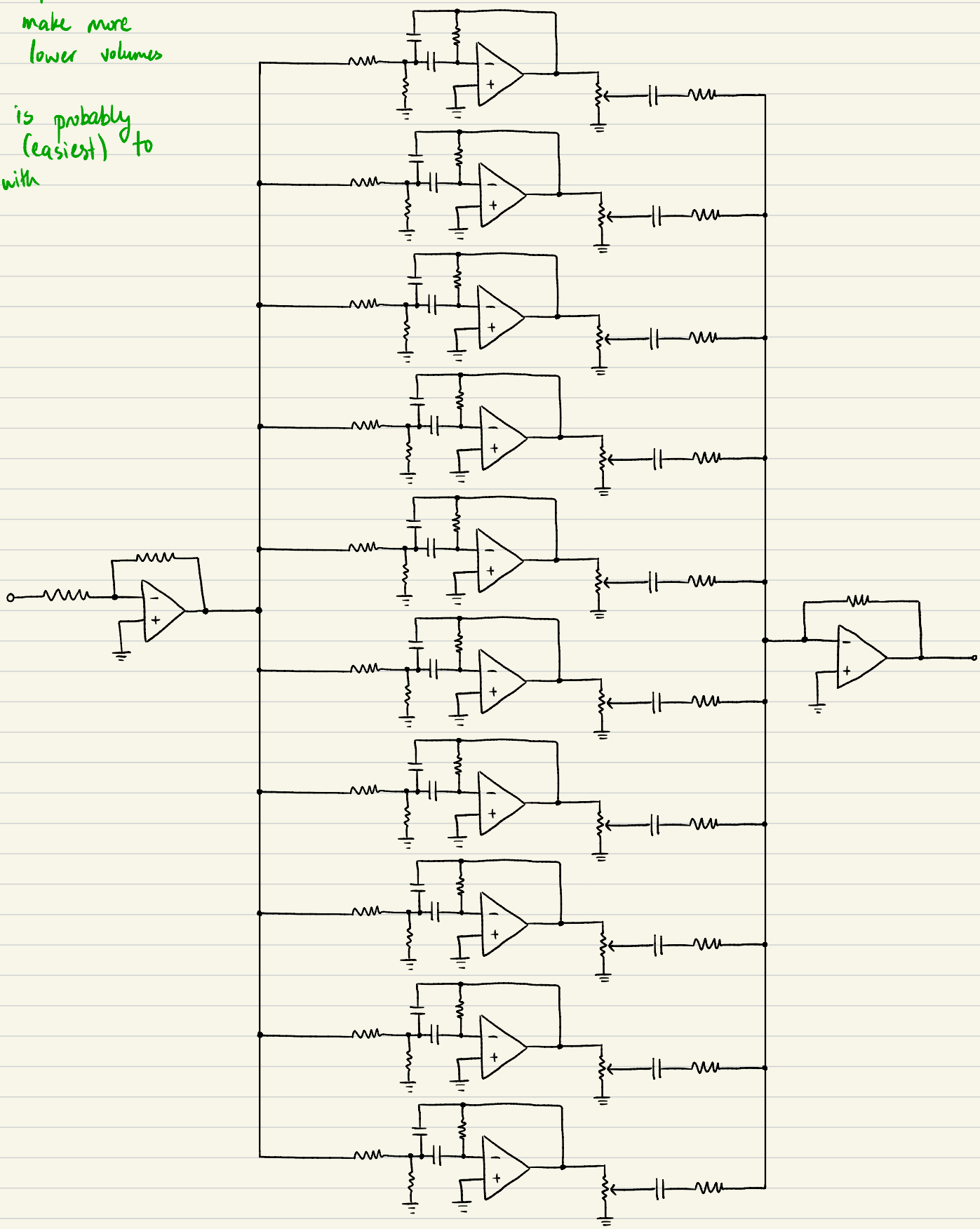
$$\frac{V_i}{R_p+R} + \dots + \frac{V_N}{R_p+R}$$

R prevents $A \to \infty$

There's nothing wrong with log taper (A1) it might make more sense for lower volumes

linear is probably safest (easiest) to work with

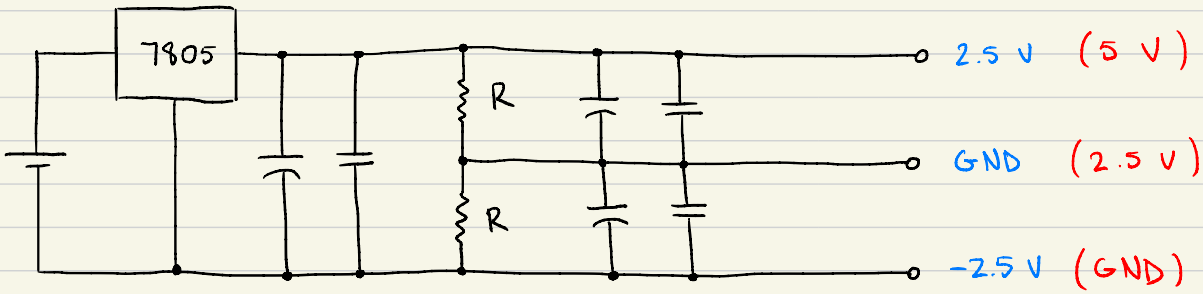
10 - Band Single - Channel Graphic Equalizer



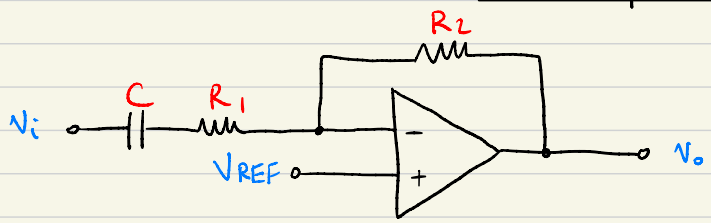
Power Supply

The op amps require a dual supply of $\pm V_{cc}$. The input power needs to be split to create a bipolar supply with a virtual ground at $\frac{V_{cc}}{2}$.

The virtual ground should only be used as a reference point for biasing the op amps. Do not use it to sink current as this will cause $\frac{V_{cc}}{2}$ to drift. Drive any loads directly from $\pm V_{cc}$.

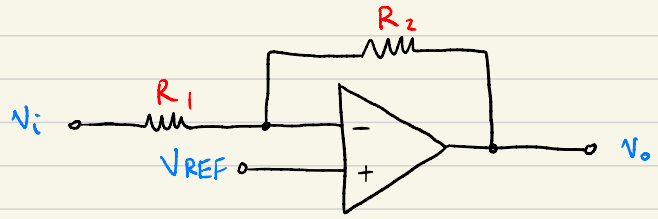


Pre - Amplifier



The preamp boosts the power of the input signal to drive the BPFs. It is actually an active LPF, which removes the DC bias and adds VGND as the new DC bias for use internally.

For AC signals, $Z_C \rightarrow 0$



$$\frac{V_i - V_{REF}}{R_1} + \frac{V_o - V_{REF}}{R_2} = 0$$

$$\boxed{V_o - V_{REF} = -\frac{R_2}{R_1}\left[V_i - V_{REF}\right]}$$

This circuit will use V_{REF} as the DC bias and operate around that point. It assumes that the input signal is biased with V_{REF}. However, any original biases from V_i have been removed by C.

$$\therefore \quad V_i - V_{REF} \Rightarrow V_{REF} = 0 \Rightarrow V_i - 0$$

$$V_o - V_{REF} = -\frac{R_2}{R_1} V_i$$

$$\boxed{V_o = -\frac{R_2}{R_1} V_i + V_{REF}}$$

This is not a full proof. The correct way to prove this is by using impedances and finding the transfer function.

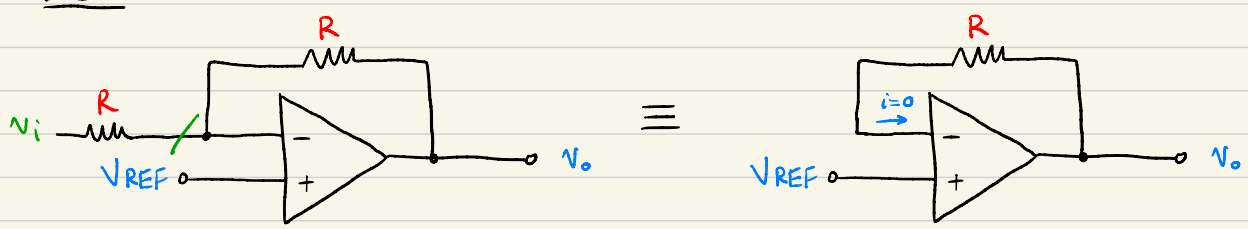
Therefore, the preamp will strip any original DC bias, add $V_{GND} = \frac{V_{DD}}{2}$ as the new bias, and output an inverted version of V_i.

The op amp will be used to supply enough current to drive all ten band pass filters.

A better proof by superposition:

$v_o = v_o^{DC} + v_o^{AC}$

<u>DC:</u>



C is an open circuit, so we get a voltage follower

<u>$v_o - V_{REF}$</u>