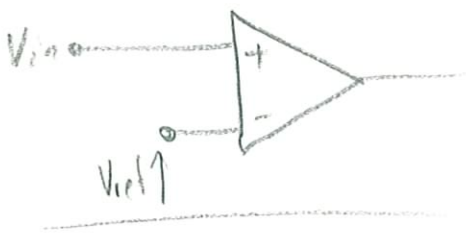
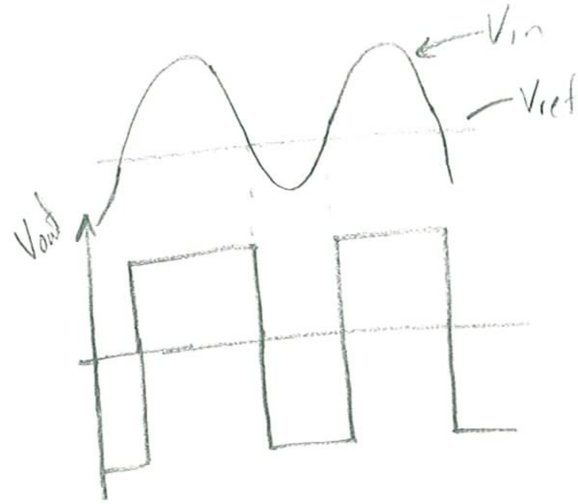
More OP-amp circuits

Comparator

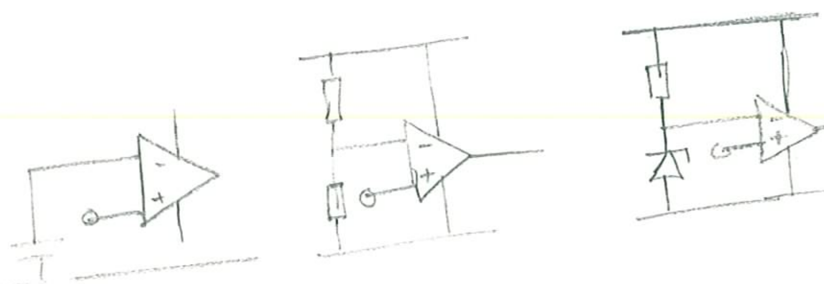
- Comparing two signals and toggle between the power feeding levels depending which is greatest

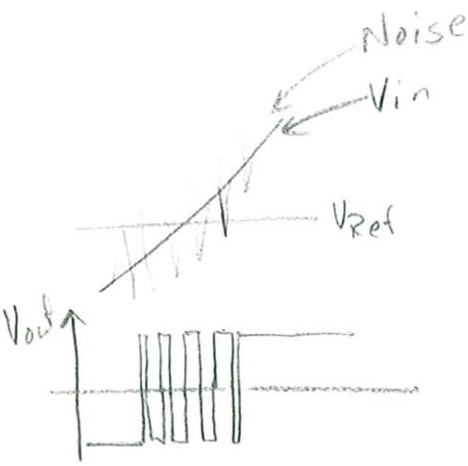




The voltage reference can either be

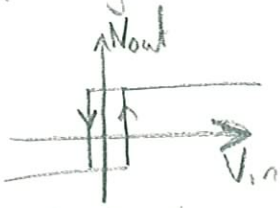
- Voltage source
- Voltage divider
- Zener diode reference



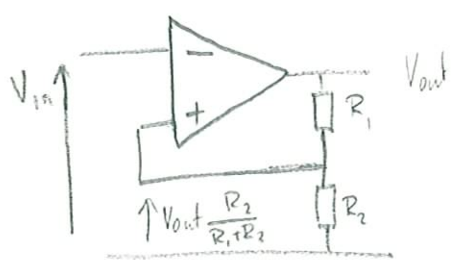


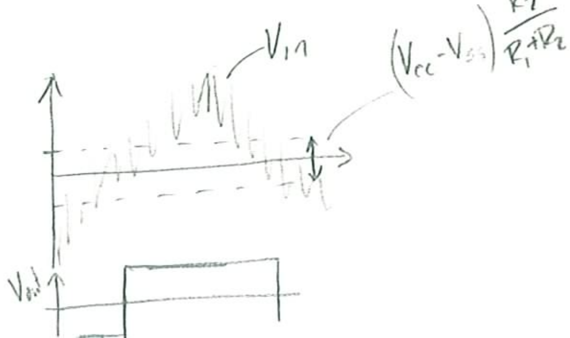
Noise on the input gives a non-distinct transition.

Reduced with hysteresis

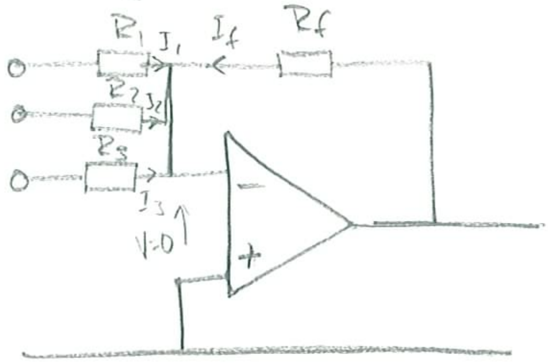


Implemented with positive feed-back





Summing amplifier



$$I_1 + I_2 + I_3 = -I_f$$

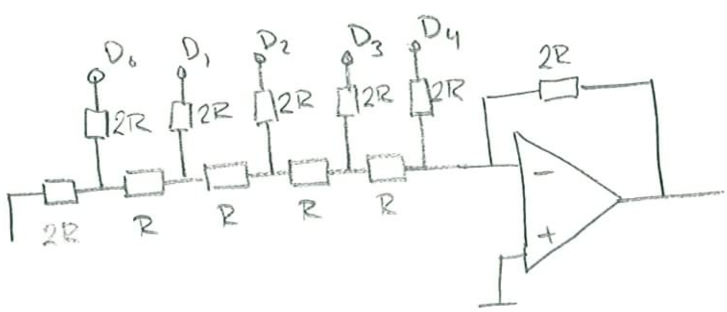
$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = -\frac{V_{out}}{R_f}$$

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \dots\right)$$

Summing	$R_1 = R_2 = R_3 = R$	$R_f = R$
Summing with amp	—— " ——	$R_f > R$
Averaging	—— " ——	$R_f = \frac{R}{3}$ or $\frac{R}{N}$
Digital to Analog conv.	$R_1 = \frac{R_2}{2} = \frac{R_3}{4} = R \dots$	$R_f = R$

An A/D converter with previos design requires largly varying resistorvalues which is difficult realizing in ICs.

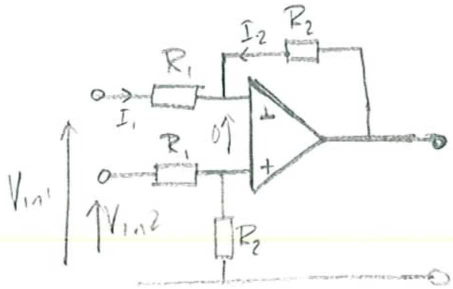
R/2R Ladder DAC



Instrumentation amplifier

Differential signals is often used in measurement system as electromagetic disturbances affets both wires similar.

Instrumentation amplifier
- Controlable gain
- Large CMRR



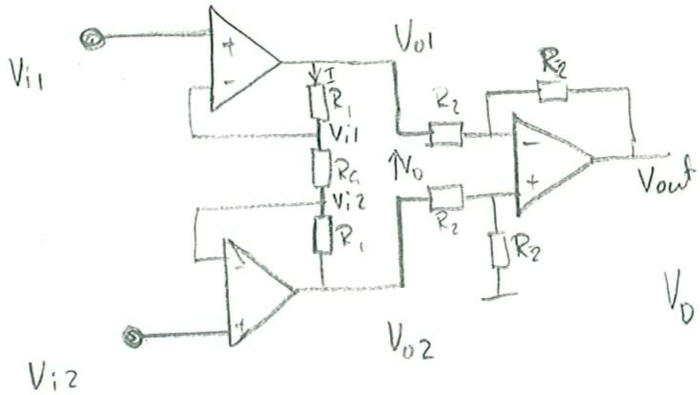
$$V_+ = V_{in2} \cdot \frac{R_2}{R_1+R_2}$$

$$\frac{V_{in1}-V_+}{R_1} = -\frac{V_{out}-V_+}{R_2}$$

$$V_{out} = \frac{R_2}{R_1}\left(V_+ - V_{in1}\right) + V_+ = V_+\underbrace{\left(1+\frac{R_2}{R_1}\right)}_{\frac{R_1+R_2}{R_1}} - V_{in1}\frac{R_2}{R_1}$$

$$V_{out} = V_{in2}\frac{R_2}{R_1+R_2}\frac{R_1+R_2}{R_1} - V_{in1}\frac{R_2}{R_1} = \underline{\frac{R_2}{R_1}\left(V_{in2}-V_{in1}\right)}$$

- Slight variations in resistor values ruins CMRR
- Different input impedance for pos and negative input



$$I = \frac{V_{i1}-V_{i2}}{R_2}$$

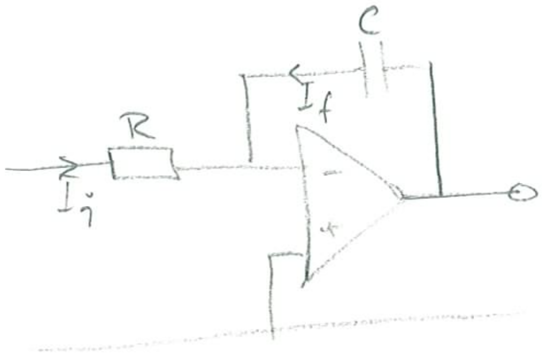
$$V_{01} = V_{i1} + R_1 I$$

$$V_{02} = V_{i2} - R_1 I$$

$$V_D = V_{01} - V_{02} = V_{11} - V_{02} + 2R_1 I = \left(V_{i1}-V_{02}\right)\left(1+2\frac{R_1}{R_2}\right)$$

When $V_{i1} = V_{i2} \Rightarrow I = 0 \Rightarrow V_{01} = 0 \Rightarrow$ Good common mode supression

Integrator



Capacitor

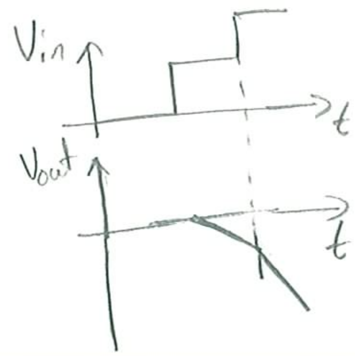
$$I = \frac{dQ}{dt} = C \cdot \frac{dV}{dt}$$

$$I_i = -I_f$$

$$\frac{V_{in}}{R} = -C \cdot \frac{dV_{out}}{dt}$$

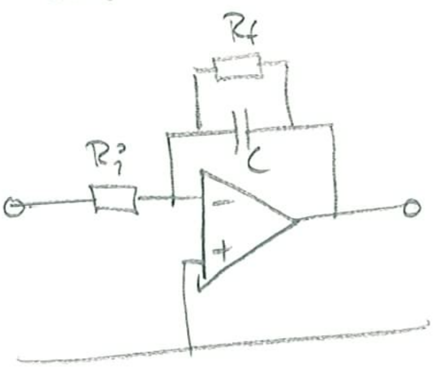
$$\frac{dV_{out}}{dt} = -\frac{1}{RC} V_{in}$$

$$V_{out} = -\frac{1}{RC}\int_0^t V_{in}\,dt$$



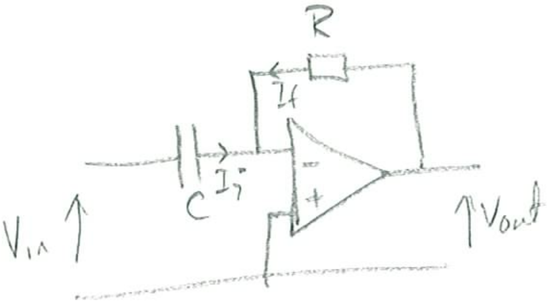
Purely capacitive feed-back

- I_{Bias} will be integrated



$R_f \gg R_i$ can overcome this issue without affecting the signal significantly.

Differentiator



$$I = \frac{dQ}{dt} = C \cdot \frac{dV}{dt}$$

$$I_i = -I_f$$

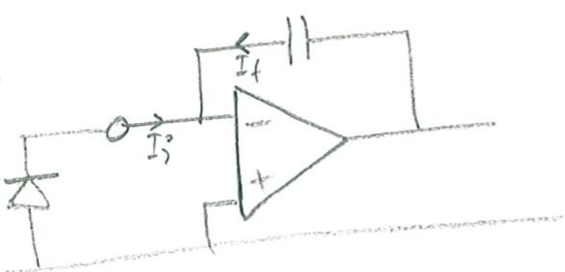
$$C \cdot \frac{dV_{in}}{dt} = -\frac{V_{out}}{R}$$

$$V_{out} = -RC \cdot \frac{dV_{in}}{dt}$$

Charge sensitive amplifier

In measurement using a photodiode for detection of total accumulated photon flux or energy in a single photon the charge needs to be measured.

$$Q = \int I \, dt$$

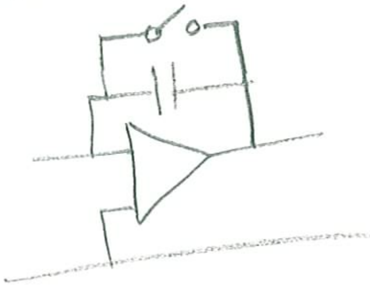


$$I_i = -I_f = -C \frac{dV_{out}}{dt}$$

$$dV_{out} = -\frac{1}{C} I_i dt$$

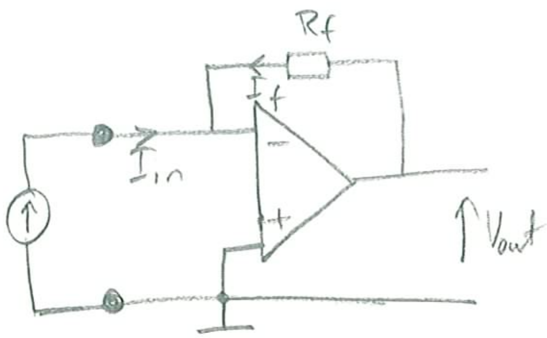
$$V_{out} = -\frac{1}{C} \int I_i \, dt$$

Needs to be resetable



Current to Voltage converter

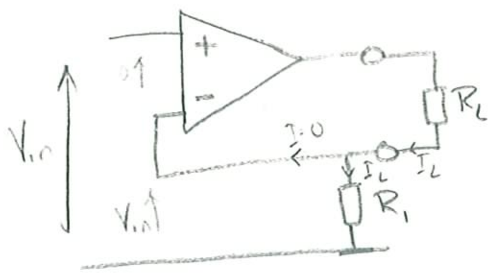
Photodiode, Current ∝ Photon flux



$$I_{in} = -I_f = -\frac{V_{out}}{R}$$

$$V_{out} = -I_{in} \cdot R$$

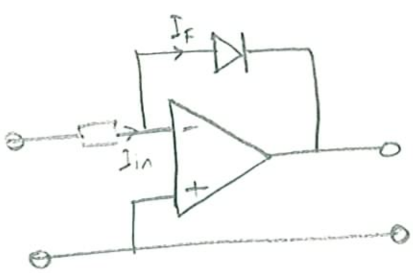
Voltage to current converter
(Current source)



$$V_{in} = R_1 \cdot I_L$$

$$I_L = \frac{V_{in}}{R_1} \quad \text{(Indepent of } R_L\text{)}$$

Logarithmic amplifier



Diode equation: $I_D = I_R e^{\frac{qV}{kT}}$

$I_{in} = I_F =$

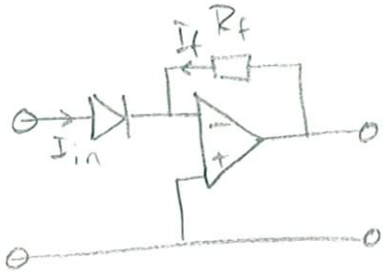
$$\frac{V_{in}}{R_{in}} = I_R e^{\frac{-qV_{out}}{kT}}$$

$$\ln \frac{V_{in}}{R_{in} \cdot I_R} = \frac{-qV_{out}}{kT}$$

($\frac{kT}{q}$: 25,9 mV @ 300 K)

$$V_{out} = -0{,}026 \ln\left(\frac{V_{in}}{R_{in} \cdot I_R}\right)$$

Antilogarithmic amplifier

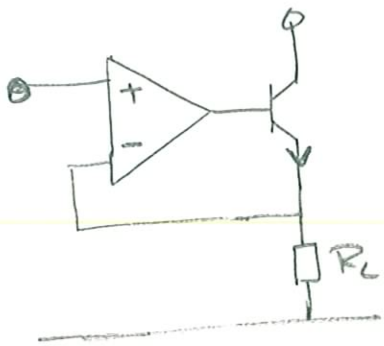


$$I_{in} = -I_f$$

$$I_R e^{\frac{qV_{in}}{kT}} = -\frac{V_{out}}{R_F}$$

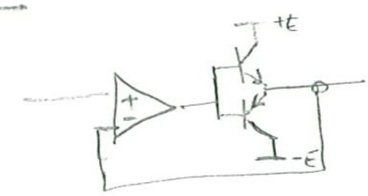
$$V_{out} = -R_F \cdot I_R e^{0{,}026 V_{in}}$$

Driving large currents

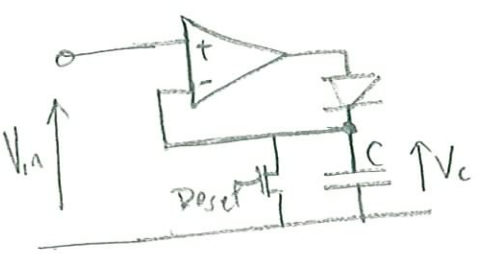


- The feed-back linearizing the non-linear performance of the transistor
- The OP-Amp only needs to drive

$$I_B \ll I_{RL}$$

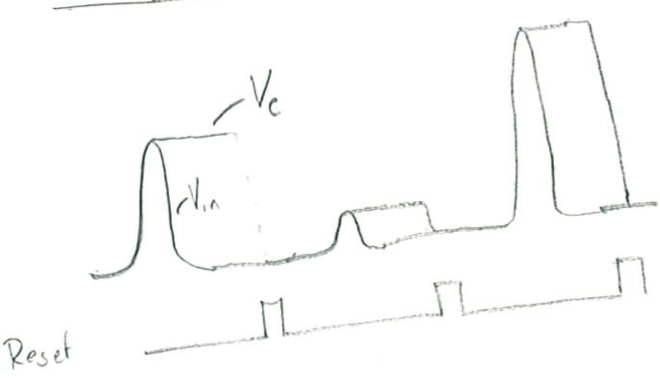


Peak detector



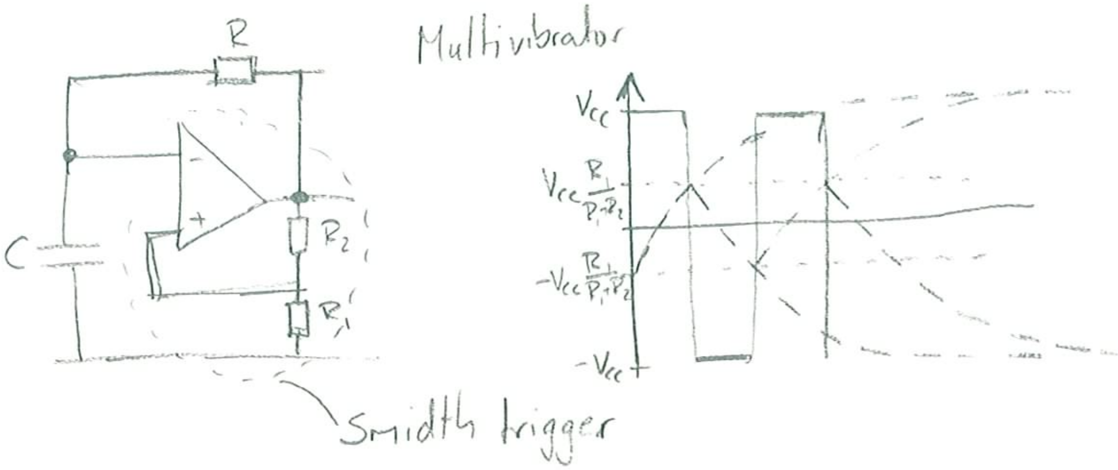
As long as $V_{in} > V_c$ the capacitor charges to $V_c = V_{in}$

As $V_{in} < V_c$ the capacitor is discharged very slowly.



Oscillators

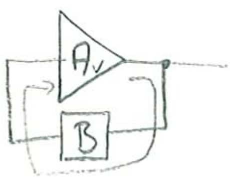
Multivibrator



$$f = \frac{1}{2RC \ln \frac{2R_1+R_2}{R_2}}$$

Conditions for oscillation

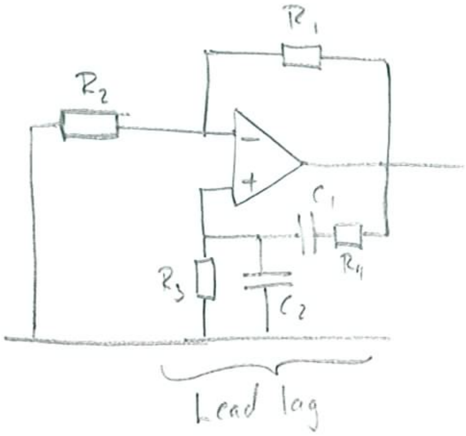
- Phase shift around the loop should be 0°
- The voltage gain around the closed loop should be 1.

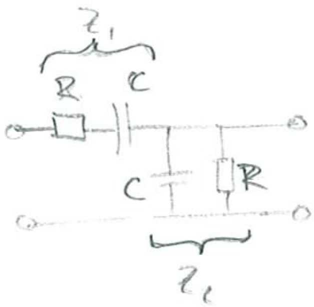


- $\phi = 0°$
- $A_{cl} = A_v \cdot B = 1$

Wien-Bridge oscillator

- RC-Oscillator
- Suitable up to 1 MHz





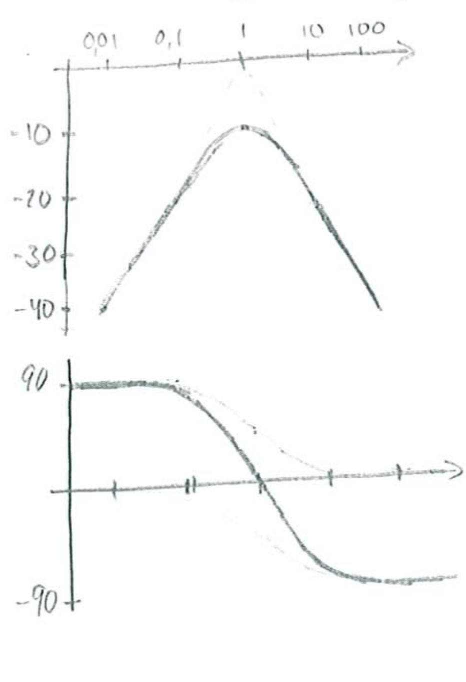
$$H(\omega) = \frac{U_{out}}{U_{in}} = \frac{Z_2}{Z_1 + Z_2} = \left/ \begin{array}{l} Z_1 = R + \frac{1}{j\omega C} \\ Z_2 = \frac{R \cdot \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{R}{1 + j\omega RC} \end{array} \right/$$

$$= \frac{\frac{R}{1+j\omega RC}}{R + \frac{1}{j\omega C} + \frac{R}{1+j\omega RC}} = \frac{R}{R + (1+j\omega RC)\left(R + \frac{1}{j\omega C}\right)} =$$

$$\frac{R}{R + R + R + j\left(\omega R^2 C - \frac{1}{\omega C}\right)} = \frac{R}{R\left(3 + j\left(\omega RC - \frac{1}{\omega RC}\right)\right)} = \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

When $\underbrace{\omega RC - \frac{1}{\omega RC} = 0}$ $\quad H(\omega) = \frac{1}{3}$ $(-9{,}5\ \text{dB})$

$\omega RC = \frac{1}{\omega RC}$ $\quad \omega = \frac{1}{RC}$



$H(\omega) = \frac{1}{3}$ with $\varphi = 0$ on V^+

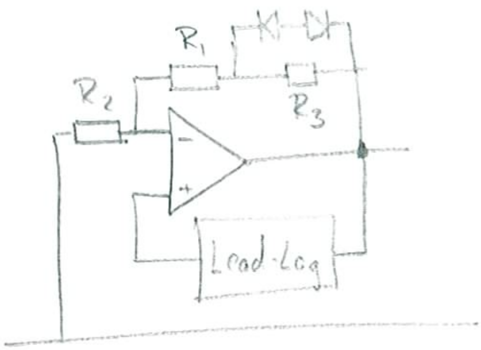
Need $H(\omega) \gtrless 3$

R_1 & R_2 forms a non-inverting amplifier

$A_v = \frac{R_1 + R_2}{R_2}$ choose $\frac{10k + 22k}{10k} = 3{,}2$ times

Amplitude stabilization

- A_v needs to be >3 for startup and be reduced to 3 at a specific amplitude.



Small amplitudes

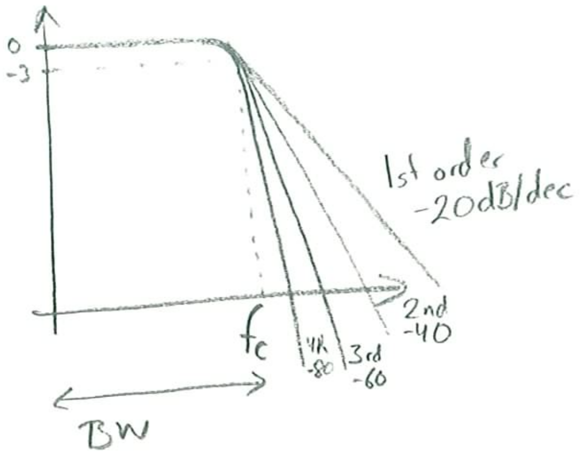
$$A_v = \frac{R_1 + R_2 + R_3}{R_2}$$

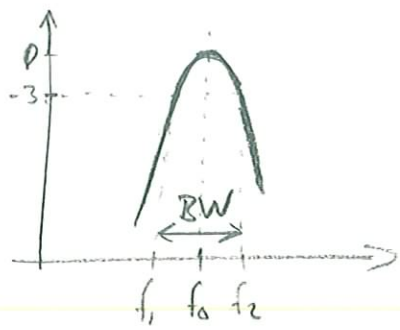
Larger amplitudes

$$A_v = \frac{R_1 + R_2}{R_2}$$

Active filters

Active filters





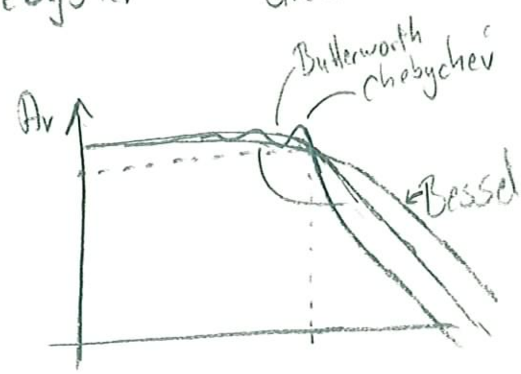
Quality factor

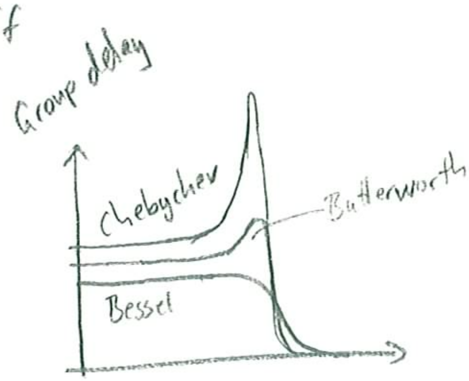
$$Q = \frac{f_0}{BW}$$

$$BW = f_{c2} - f_{c1}$$

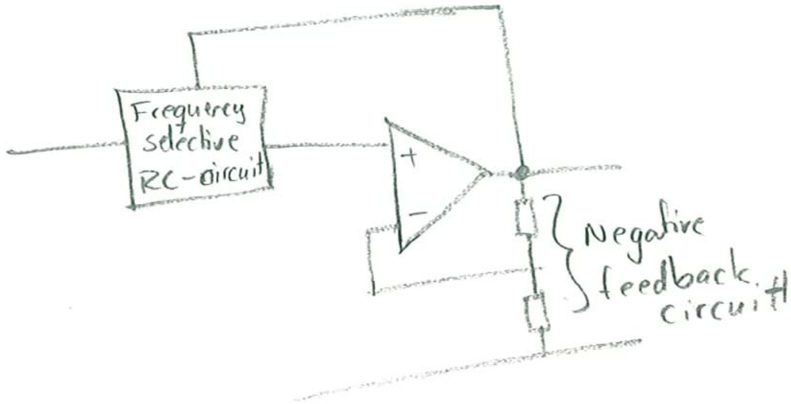
$$f_0 = \sqrt{f_{c1} \cdot f_{c2}}$$

Filter response characteristics
- Higher order filters can be tailored depending on situation
- Three main charateristics
  - Bessel - Linear phase (Minimum distortion, delay circuit)
  - Butterworth - Maximally flat gain response
  - Chebyshev - Greatest roll-off



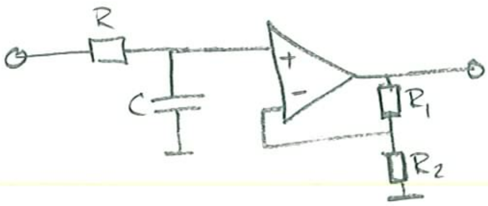


General active filter

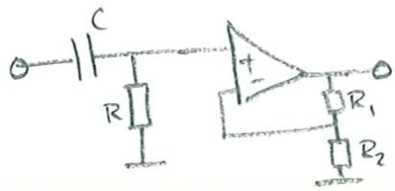


First order

LP



HP



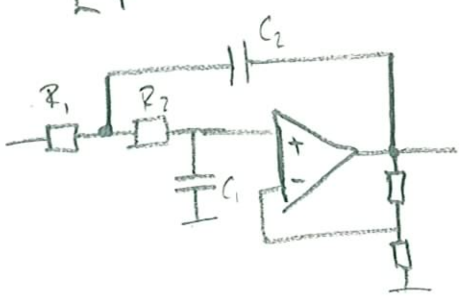
Second order filters

Two major topologies

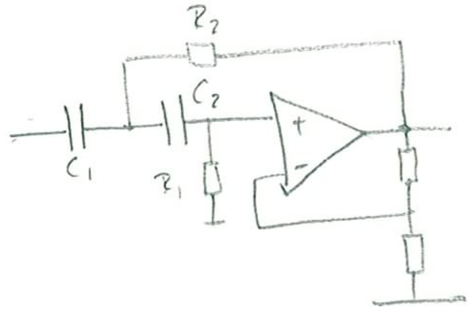
- Sallen Key
- Multiple feedback

Sallen Key

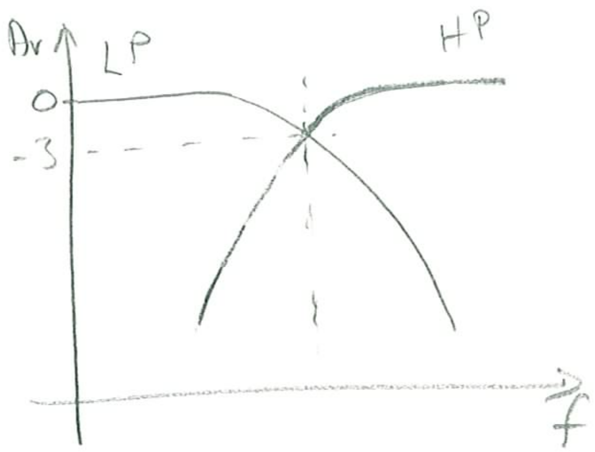
LP



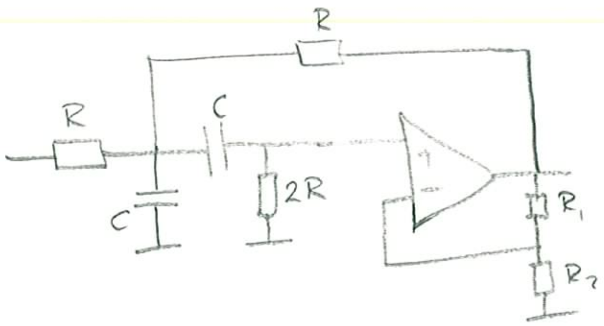
HP



- Resistor and capacitance values are calculated with help from tabulated values
- By swapping components in a LP filter to a HP configuration a HP-filter with same parameters are achieved

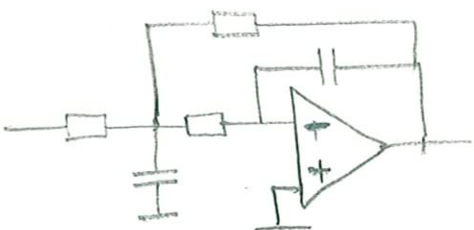


B P

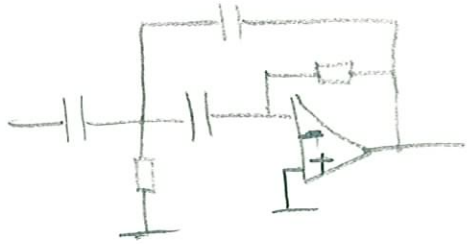


Multiple feed-back
⇒ often used in applications requireing high Q and high gain.

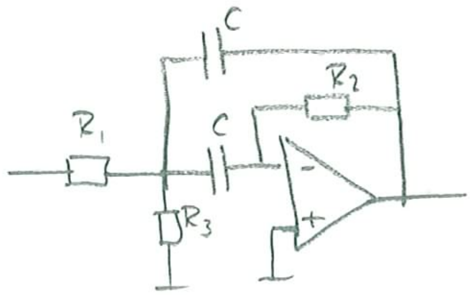
LP



HP



BP



⇒ Higher order filters is achieved by cascading 2nd order filters