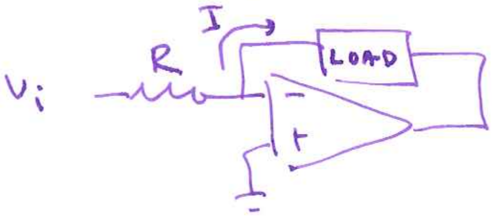
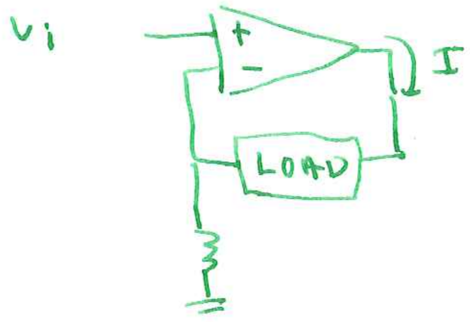
Current sources — supplies a fixed current – if R is big a big voltage results; if R small → small voltage. Every current source has its limits – if R is too big will not be able to produce required voltage.

[Contrast: voltage sources supply fixed voltage – if R is big a small current results; if R small → large current. Every voltage source has its limits – if R is too small will not be able to produce required current]

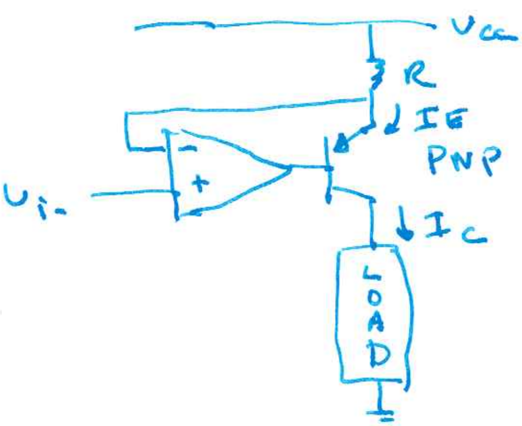


$I = \frac{V_i}{R}$



$I = \frac{V_i}{R}$

Above require a "floating" load – often want load connected to ground. Also above limited by current output of op-amp → a few mA



Since $I_E \approx I_C$

$I_C \approx \frac{V_i}{R}$

Vocabulary

AC or DC amp

band width (f_{-3dB}) ; "mid band" gain

inverting / non inverting

clipping

differential amp (out $= A_d(V_+ - V_-)$)

- common mode gain (where $V_+ = V_- = V_{in}$) A_c
- differential gain (where $V_+ - V_- = V_{in}$) A_d
- common mode rejection ratio $= \frac{A_d}{A_c}$ (often in dB)

noise - note odd unit $\mu V/\sqrt{Hz}$ or $pA/\sqrt{Hz}$

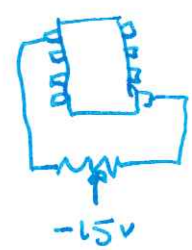
For op-Amps

Gain-Bandwidth product [note Compensated op-Amps]

Slew rate

"rail-to-rail" or limited output voltage swing

input offset voltage - "as if"

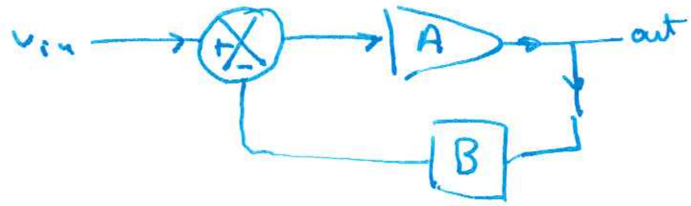


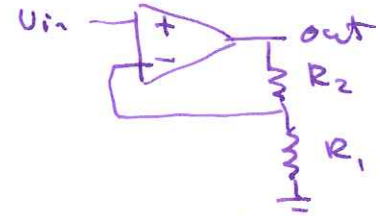
input bias current

open loop gain

Feedback — some notation & algebra to show that "things get better if you 'throw away' gain"

Notation:





$$A(V_{in} - BV_{out}) = V_{out}$$

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

Remark: not related to transistor β

$$V_{in} = \left(B + \frac{1}{A}\right) V_{out}$$

$$\frac{1}{\left(B + \frac{1}{A}\right)} = \frac{V_{out}}{V_{in}} \leftarrow \text{circuit gain}$$

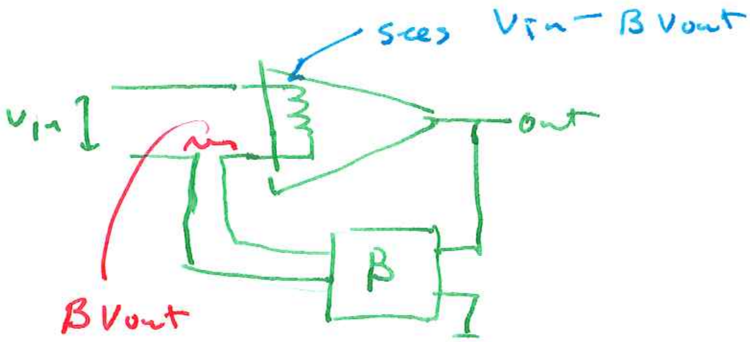
} in contrast to op amps gain

$$= \frac{1/B}{\left(1 + \frac{1}{AB}\right)}$$

$$\leftarrow \frac{R_1 + R_2}{R_1} = 1 + R_2/R_1$$

AB sometimes called the "loop gain" A_L

alternate form

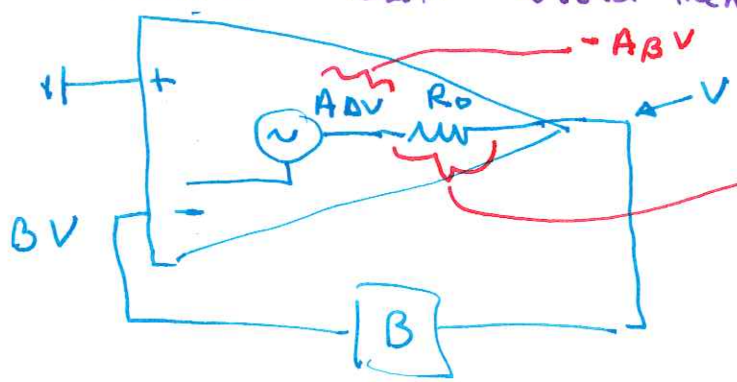


Note: the above is negative feedback; positive feedback → expo growth and is generally a bad idea.

The invention of negative feedback amps is attributed to Harold Black — EE working at Bell Labs — 1927

Output Impedance – a trick to mathematically calculate a circuit output impedance. Consider $V_{in}=0$ ("ground the input") this (in theory) would produce $V_{out}=0$ but we (mathematically) apply an external voltage V to the output & calculate the resulting current, I. The circuits output impedance is the V/I.

(In an experimental situation we'd more like remove current from amp – by applying a load – and measure the resulting voltage droop – the circuits ~~Rout~~ Z_{out} would then be $\frac{\Delta V}{I}$)



voltage drop $= V - {}^{-}A\beta V$

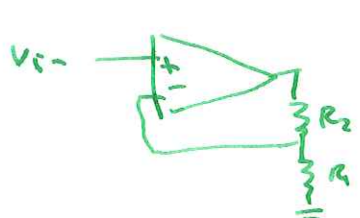
$= (1+A\beta)V$

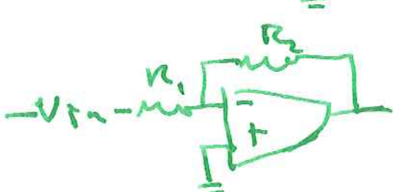
current $= \dfrac{\text{voltage drop}}{R_o}$

$$Z_o = \frac{V}{I} = \frac{R_o}{(1+A\beta)}$$ ← note reduced from what was probably a small R_o to begin with.

$$I = \frac{(1+A\beta)V}{R_o}$$

Slight practical consideration – in real circuit feedback network β itself would draw some current





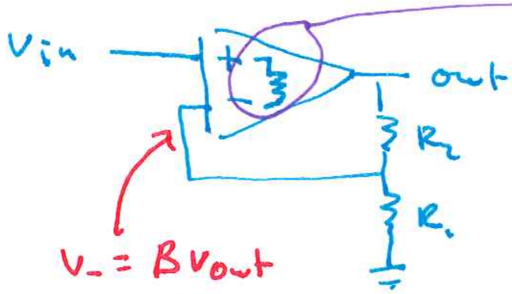
in both cases an addition current flow of $V/_{R_1+R_2}$ happens – ie must add this current to above

result: $Z_{out} = \underbrace{\frac{R_o}{(1+A\beta)}} \,||\, R_1+R_2$

this should be much smaller than R_1+R_2 so

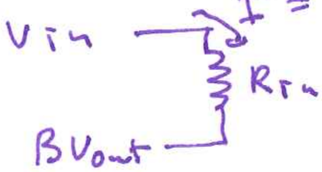
$Z_o \approx R_o/(1+A\beta)$

Input Impedance (Note: for inverting amp circuit this will be R which is not huge — say kΩ)



$V_- = BV_{out}$

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



$$I = \frac{V_{in} - BV_{out}}{R_{in}} = \frac{V_{in}}{R_{in}}(1 - BG)$$

$$G = \frac{V_{out}}{V_{in}} = \frac{A}{1 + BA}$$

$$\frac{V_{in}}{I} = \frac{R_{in}}{(1 - BG)} = \frac{R_{in}}{\left(1 - \frac{AB}{1+BA}\right)}$$

$$= \underbrace{R_{in}(1 + BA)}$$

an initially large value increased even more.