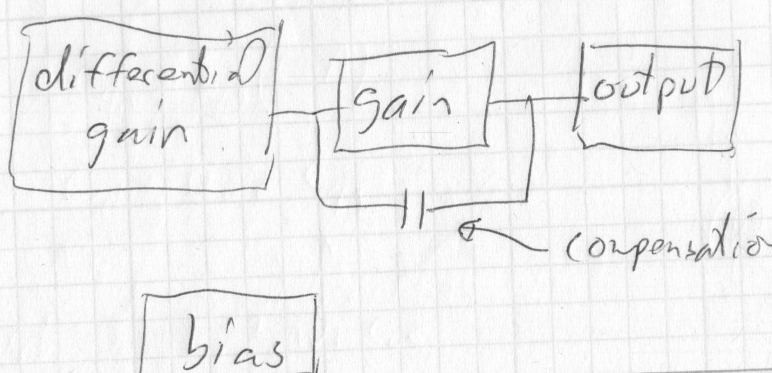
Midterm - nice!

op-amps
"operational" ?
2 stage

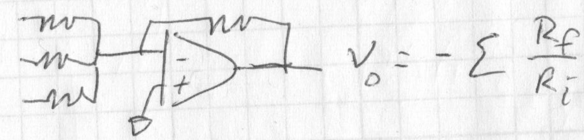
bias network

early days: tube amps K-2W 1951
then discrete NPN
integrated NPN, NPN+PNP



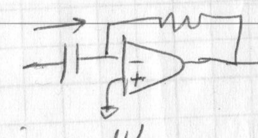

(PVT independent)

Op-amps
operational amplifiers - before computers
↳ addition, subtraction



$V_o = -\sum \frac{R_f}{R_i} V_i$

↳ integrals & derivatives

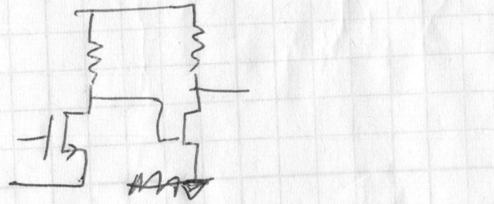


$V_o = -RC \frac{dV_i}{dt}$

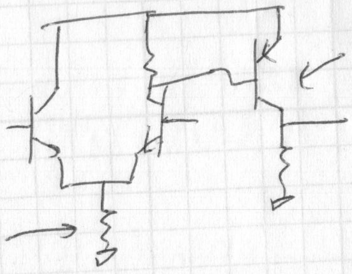
$i = C \frac{dV}{dt}$

integral, log, exp.

2 stage op-amp
simplest



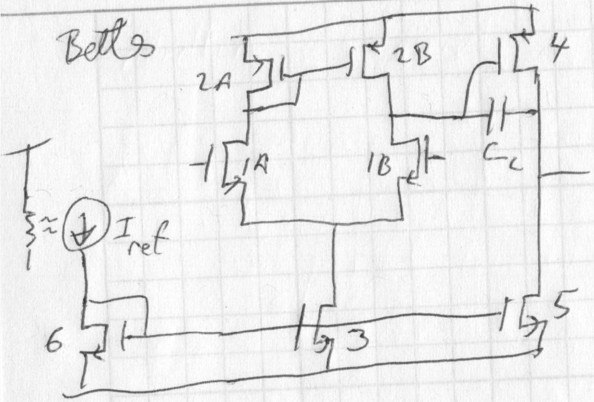
better



why pnp or pmos?

why tail resistor?
(1936)

Both




| | |
|---|---|
| diff pair | 1AB |
| active load | 2AB |
| gain stage | 4/5 |
| output stage | none |
| bias network | 6,3,5 |
| signal path | 1,2,4 |
| compensation capacitor | $C_c$ |

input common mode range

output swing

frequency response

common mode rejection ratio

power supply rejection ratio (gain)

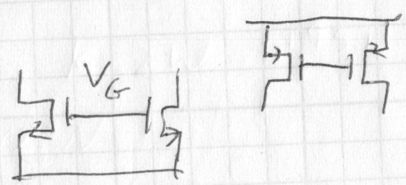
input offset

noise

We will look at other topologies as well

Bias network

current mirror




assuming: identical transistors
both in saturation

$\lambda = 0$

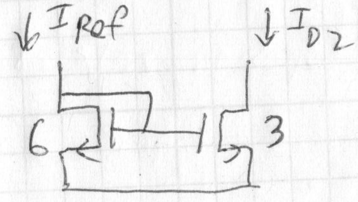
How different can $I_{D1}$ and $I_{D2}$ be?

A: 0

What if $\lambda \neq 0$?

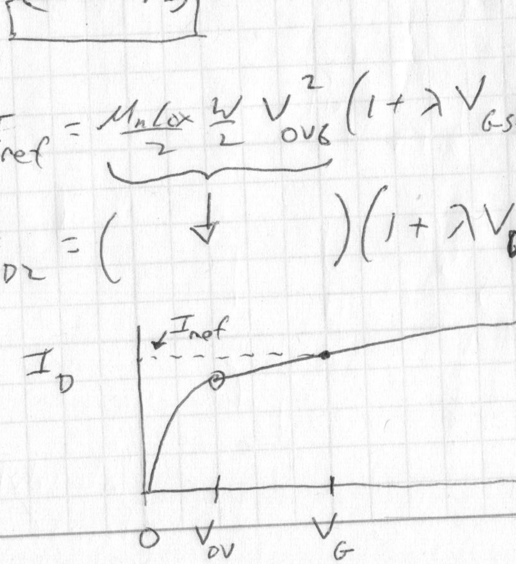
$I_D = I_{D0}(1 + \lambda V_{DS})$

$\Delta I_D = I_{D0}\,\lambda\,\Delta V_{DS}$ $\qquad \frac{\Delta I}{I_D} = \lambda \Delta V_{DS}$




$I_{ref} = \frac{\mu_n C_{ox}}{2}\frac{W}{L} V_{OV6}^2 (1 + \lambda V_{GS6})$

$I_{D2} = (\quad\downarrow\quad)(1 + \lambda V_{DS3})$




$I_{D2}$ can be less than, greater than or equal to $I_{ref}$

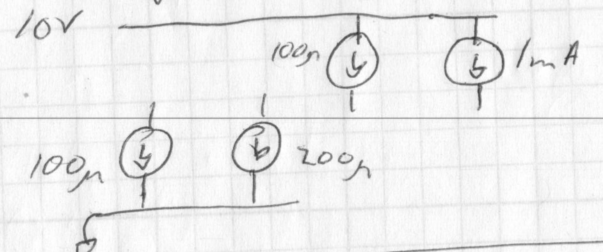
$|V_{th}| = 1$ $\mu_n C_{ox} = 50 \frac{\mu A}{V^2}$ $\mu_p C_{ox} = 25 \frac{\mu A}{V^2}$

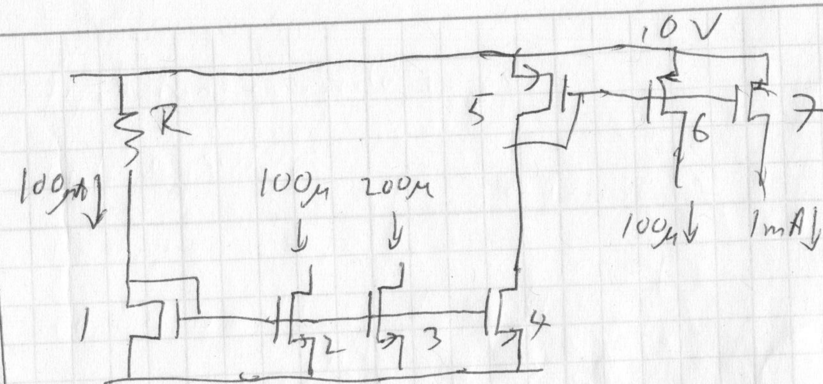
$V_{DD} = 10\ V$ assume $\lambda = 0$

want a $100\mu A$ sink, $200\mu A$ sink

$100\mu A$ source $1mA$ source

swing to within $0.2\ V$ of rails




pick $V_{ov1} = 200mV$

$$I_{D1} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_1 V_{ov1}^2 = 25\frac{\mu A}{V^2}\left(\frac{W}{L}\right)_1 (0.2V)^2$$

$$= 1\mu A \left(\frac{W}{L}\right)_1 \Rightarrow \left(\frac{W}{L}\right)_1 = 100$$

$$I_{D2} = I_{D1}\frac{(W/L)_2}{(W/L)_1} \Rightarrow \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_1 = 100$$

$$I_{D3} = 200\mu A \Rightarrow \left(\frac{W}{L}\right)_3 = 2\left(\frac{W}{L}\right)_1 = 200$$

pick $I_{D4} = I_{D1} \Rightarrow \left(\frac{W}{L}\right)_4 = 100$

need $|V_{ov5}| \leq 200mV$ pick $200mV$

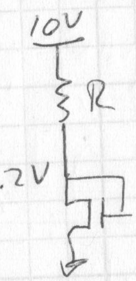
$$100\mu A = I_{D5} = \frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)_5 (V_{ov5})^2$$

$$= \frac{25\mu A/V^2}{2}\left(\frac{W}{L}\right)_5 (0.2V)^2$$

$$\Rightarrow \left(\frac{W}{L}\right)_5 = 200$$

$$\left(\frac{W}{L}\right)_6 = \left(\frac{W}{L}\right)_5 = 200$$

$$\left(\frac{W}{L}\right)_7 = 10\left(\frac{W}{L}\right)_5 = 1,000$$




$$R = \frac{10 - 1.2V}{0.1mA} = 8.8K$$

what if $V_{DD}$ varies? $V_{th}$ varies? R varies?