Midterm 1
Midterm 2 Friday March 23 80 minutes
HW 5

Op-amps

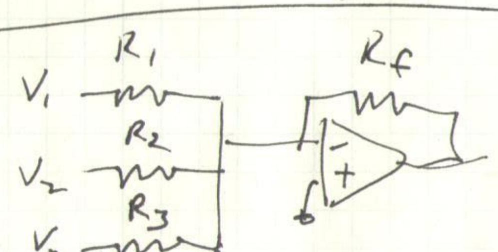
mathematical operation amplifiers
(e.g. EE128 lab up to ~1980)
before computers, analog computation only
today, still best choice in some situations
we get to decide when to use digital/analog.

Examples: based on virtual ground.

$i_f = -i_{in}$

$i_f = \frac{v_o}{Z_f}$

e.g.

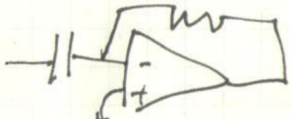


$V_o = i_f R_f$

$= -i_{in} R_f$

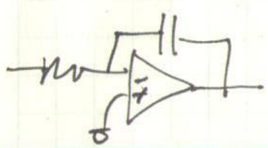
$= -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$

⇓



$i_{in} = C\frac{dv_{in}}{dt}$

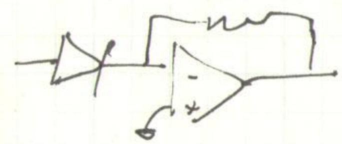
$v_o = -R_f C \frac{dV_{in}}{dt} \Rightarrow$



$v_o = -\int \frac{V_i}{RC} dt \Rightarrow$

linear ODEs! Apollo!

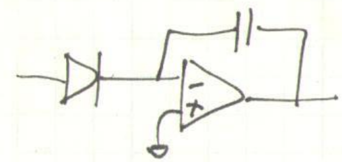
Nonlinear



exp

log

With a log table, even adders can multiply!



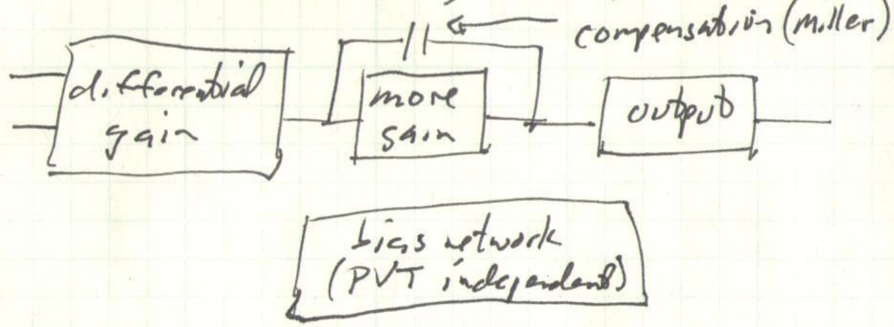
?

How? tubes K2-W 1951

discrete NPN

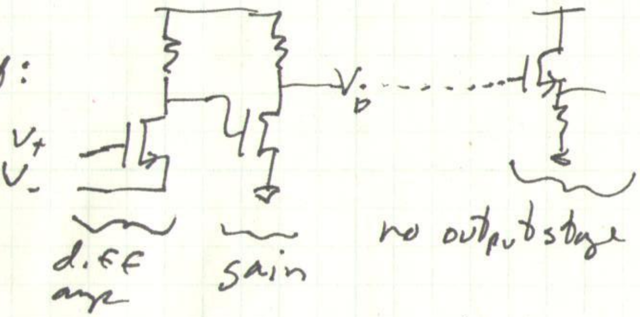
integrated NPN → NPN + PNP

integrated PMOS, NMOS, CMOS



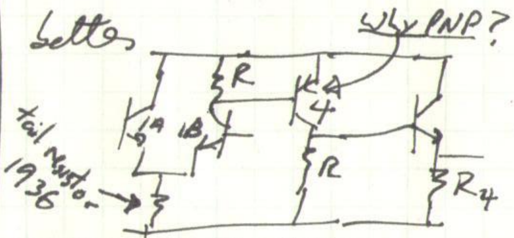
2 stage

simplest:



lousy input offset, common mode, etc.

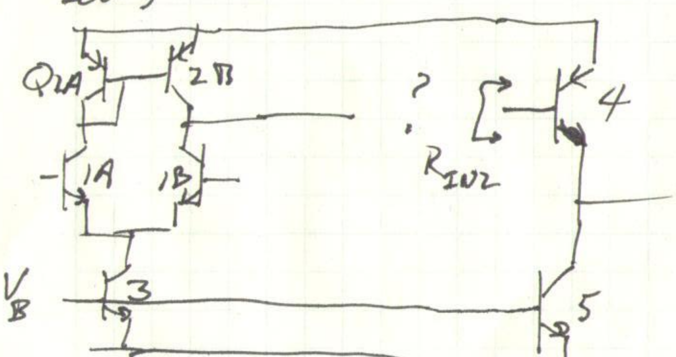
better



output resistance $= R_4 \| \frac{1}{g_m}$

$\approx \frac{1}{g_m}$

better



R_{IN2} too small

$\frac{\beta}{g_m} = \frac{\beta V_{TH}}{I_c}$

$\approx \frac{5V}{I_c}$

compare to

$\frac{V_A}{I_c} \approx \frac{100V}{I_c}$

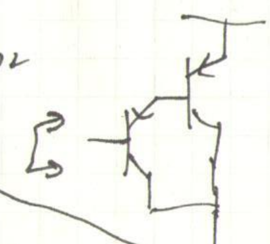
Q3: better common mode rejection

Q2B: better output resistance ⇒ gain

Q2A: easy biasing, 2x better G_m

Q5: better output resistance ⇒ gain

increase R_{IN2}



$R_E = \frac{\beta}{g_{m4}}$

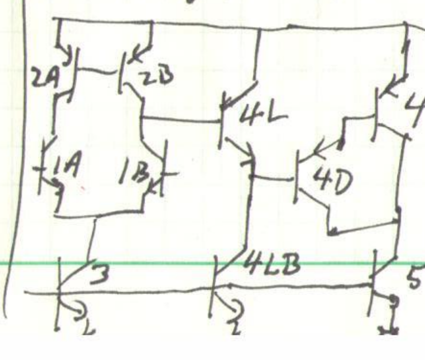
$\beta R_E = \frac{\beta^2}{g_{m4}} = \frac{\beta^2 V_{TH}}{I_{c4}}$

probably large compared to $\frac{V_A}{I_{c3}}$

but bias point is off.

2 diodes below the rail

so bring it back



4D Darlington - increase Rin

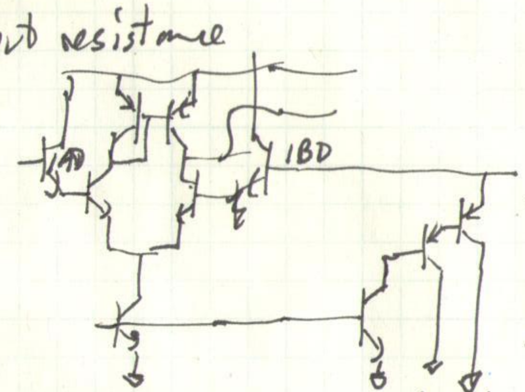
4L level shifting emitter follower (and Darlington)

4LB bias for 4L

≈ LM374 [illegible]

~~CMOS~~ version

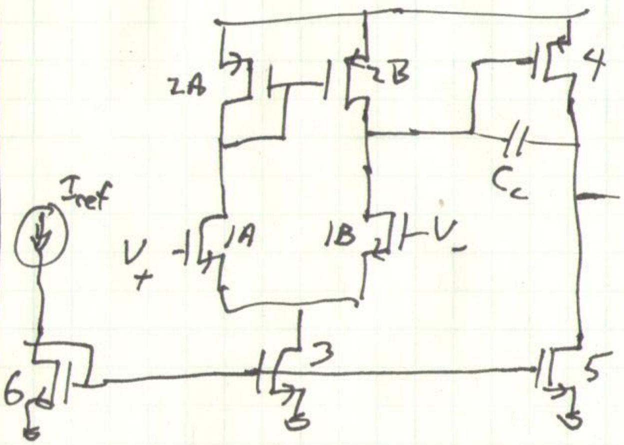
input resistance

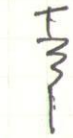


conceptually OK. Bad in practice

Even better: measure input current and subtract it out

CMOS version – 2 stage (workhorse)



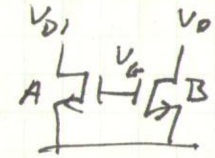
I_{ref}: 

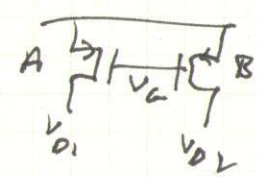
initially

typically no output stage

Diff pair	1AB	differential gain
Active load	2AB	common mode gain
gain stage	4,5	input offset
bias network	3,5,6	input common mode range. output swing
signal path	1,2,4	frequency response
		power supply rejection
		noise
		current drive slew rate

current mirrors





if A and B have Same $\frac{W}{L}$, V_t, μC_{ox} and $\lambda = 0$ how different can the current be if both are in saturation?

A: not at all different

What if $\lambda \neq 0$?

$$\frac{\Delta I_D}{I_{DA}} = \lambda \Delta V_D = \frac{\Delta V_D}{V_A}$$