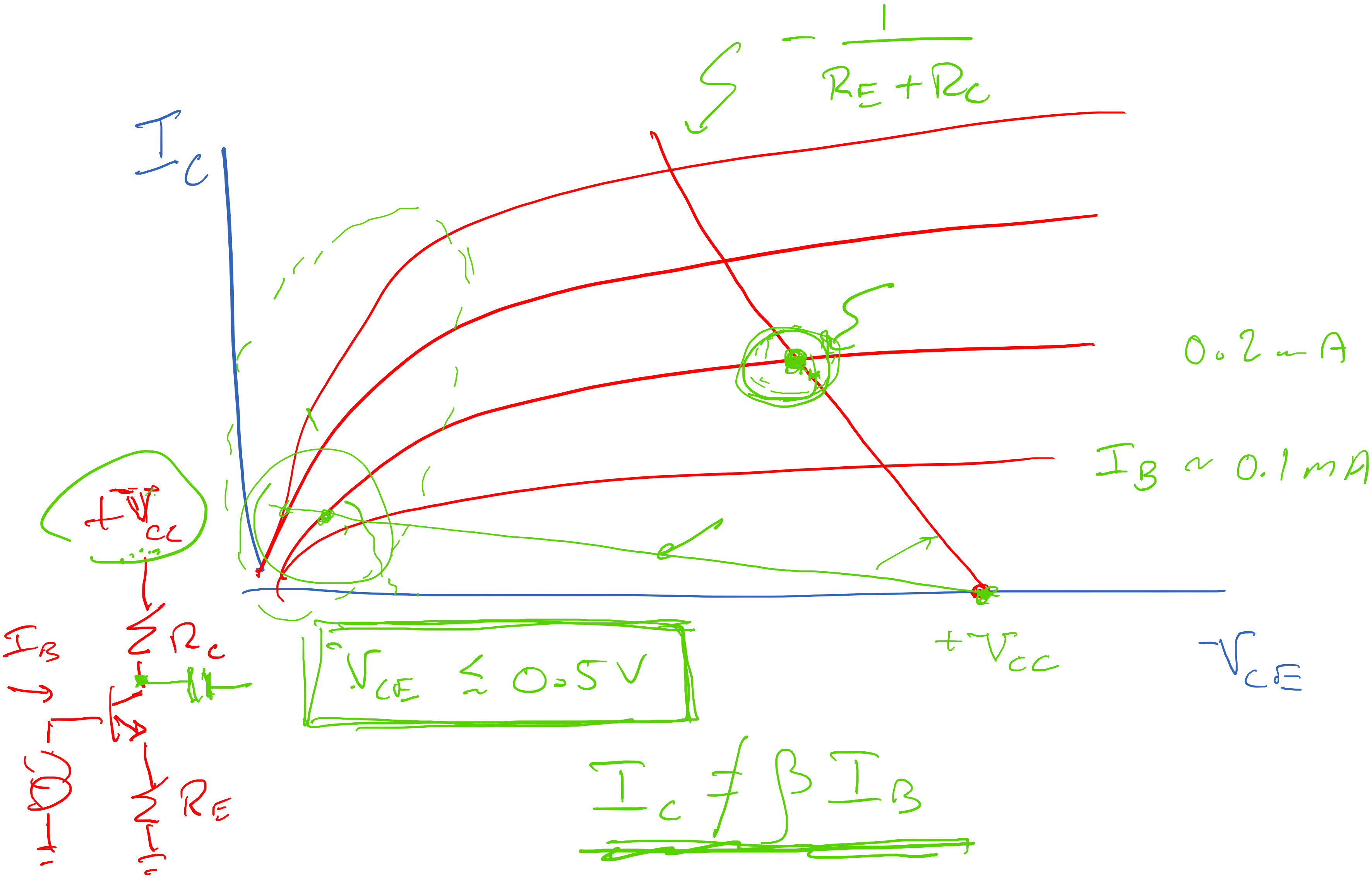
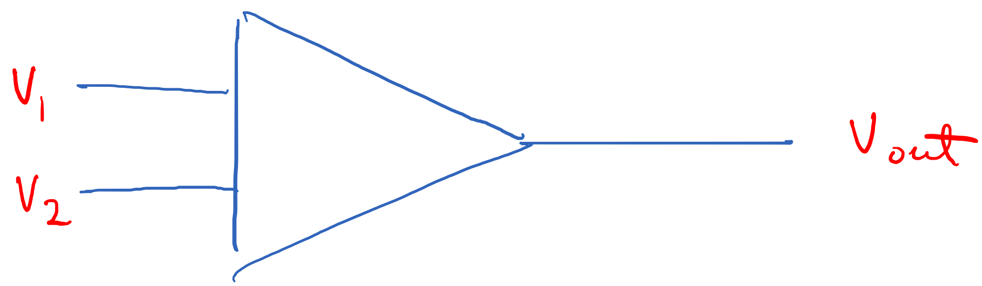


I_C
$-\frac{1}{R_E+R_C}$
0.2 mA
$I_B \sim 0.1$ mA
$+V_{CC}$
V_{CE}
$V_{CE} \lesssim 0.5$ V
$I_C \neq \beta I_B$
$+V_{CC}$
R_C
I_B
R_E

DIFFERENCE AMPLIFIER



DEFINE

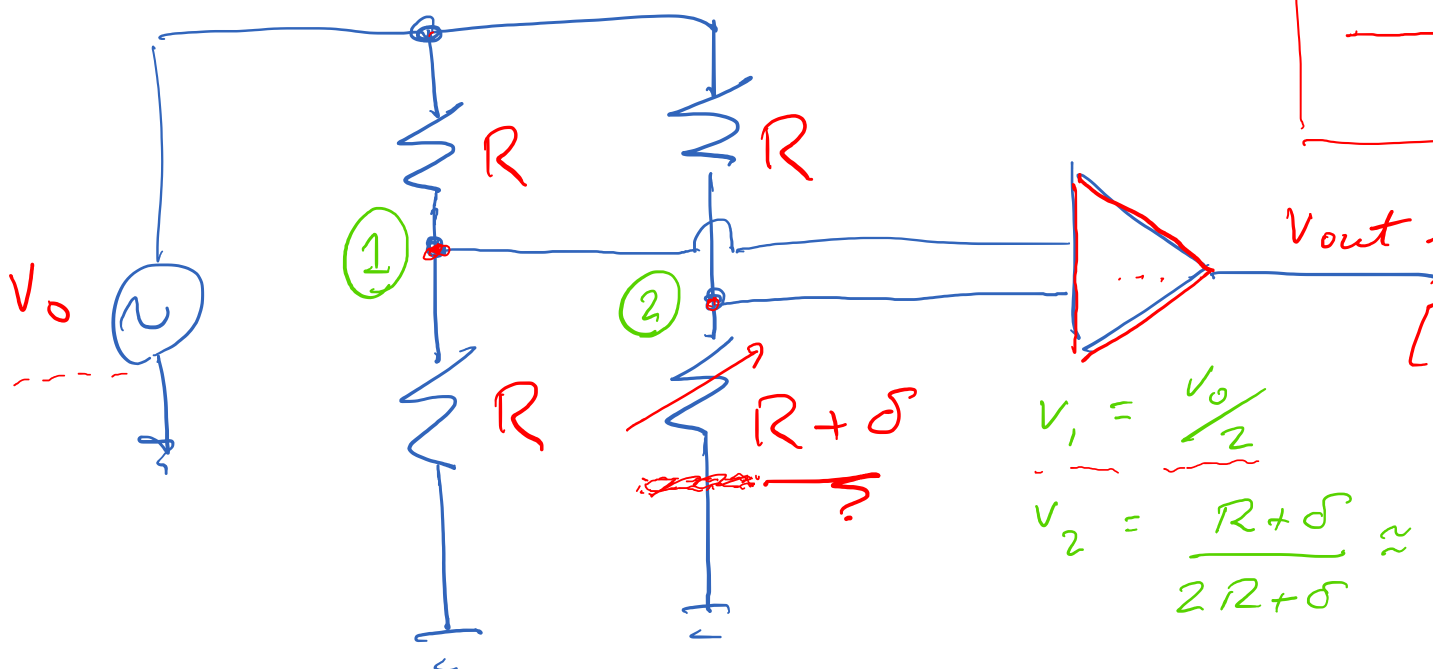
$$V_{cm} = \frac{V_1 + V_2}{2}$$

$$V_D = V_1 - V_2$$

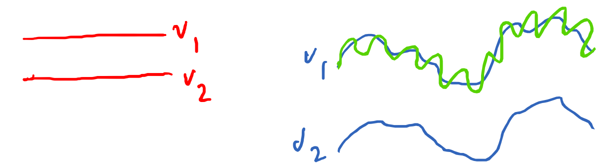
$$V_{out} = A_{cm} V_{cm} + A_D V_D$$

EXAMPLE

WHEATSTONE BRIDGE



ALSO, COMMON MODE NOISE PICKUP



$V_{out} \approx A_D V_D$

$[A_{cm} \ll A_D]$

$V_1 = V_0/2$

$$V_2 = \frac{R+\delta}{2R+\delta} \approx \frac{V_0}{2}\left[1+\frac{\delta}{R}\right]\left[1-\frac{\delta}{2R}\right]$$

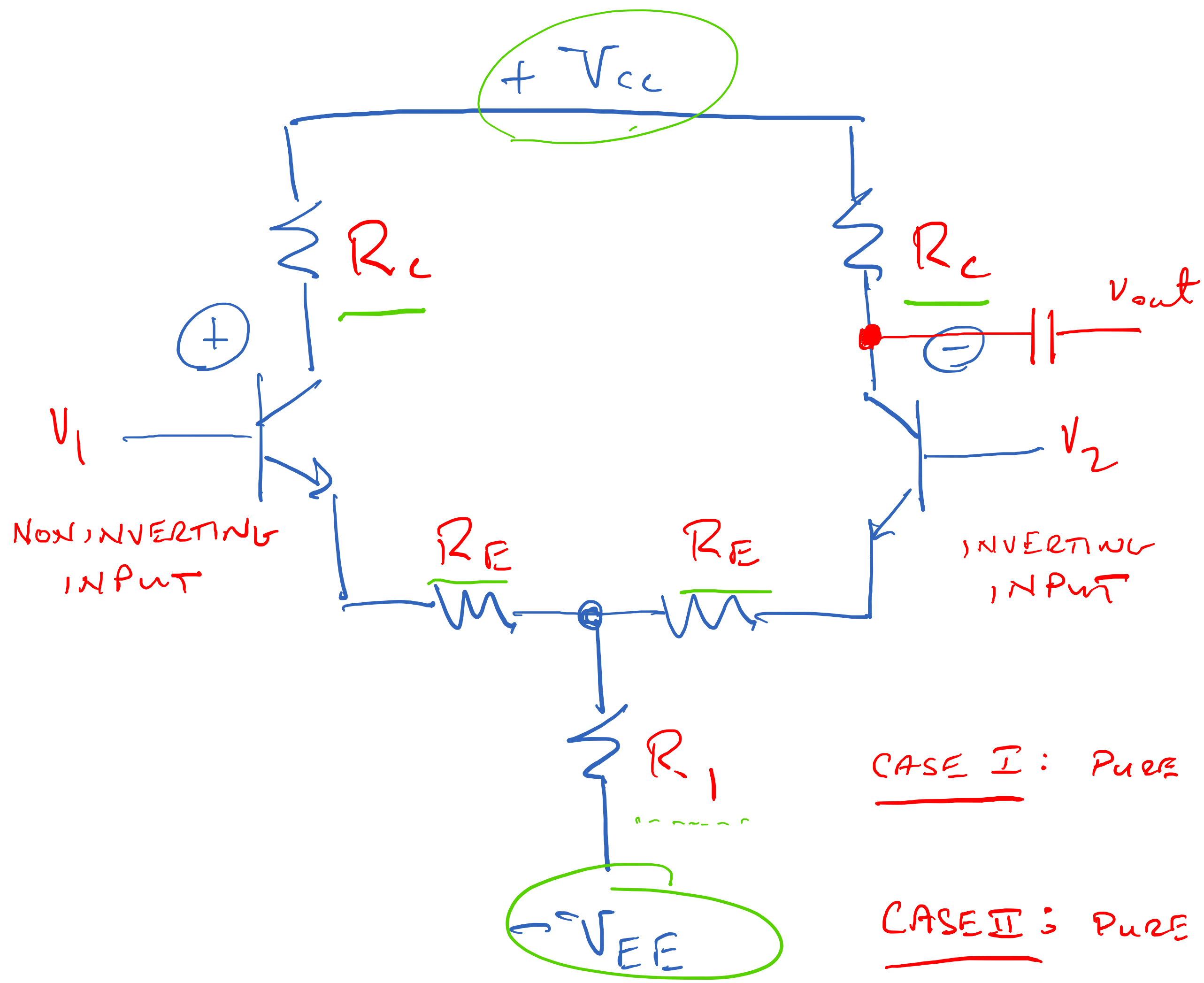
$$\approx \frac{V_0}{2}\left[1+\frac{\delta}{2R}\right]$$

$$V_D = \frac{\delta}{4R} V_0$$

$$\frac{V_0}{2} \gg \frac{\delta}{4R} V_0$$

e.g.
10-BIT A/D
1 : 10^3 RESOLUTION

BJT DIFF AMP: "LONG-TAILED PAIR"



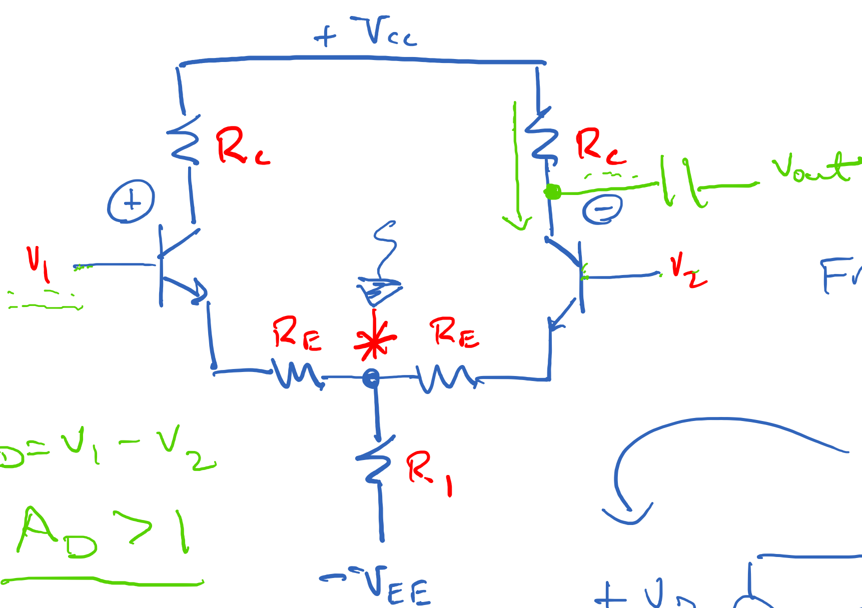
SEPARATELY ANALYZE

DIFFERENTIAL and COMMON-MODE RESPONSE

CASE I: PURE DIFF INPUT: $v_1 = +\frac{V_D}{2}$, $V_2 = -\frac{V_D}{2}$

CASE II: PURE C.M. $V_1 = V_2 = V_{CM}$

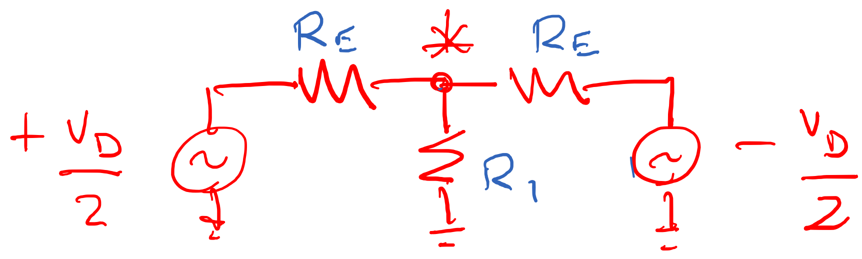
DIFFERENTIAL MODE



$V_D = V_1 - V_2$

$A_D > 1$

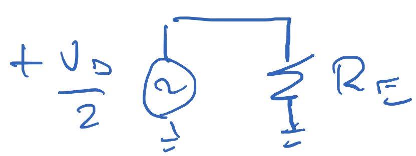
WHAT IS V_* ?



From superposition/symmetry,

$$V_* = 0$$

"VIRTUAL GROUND"



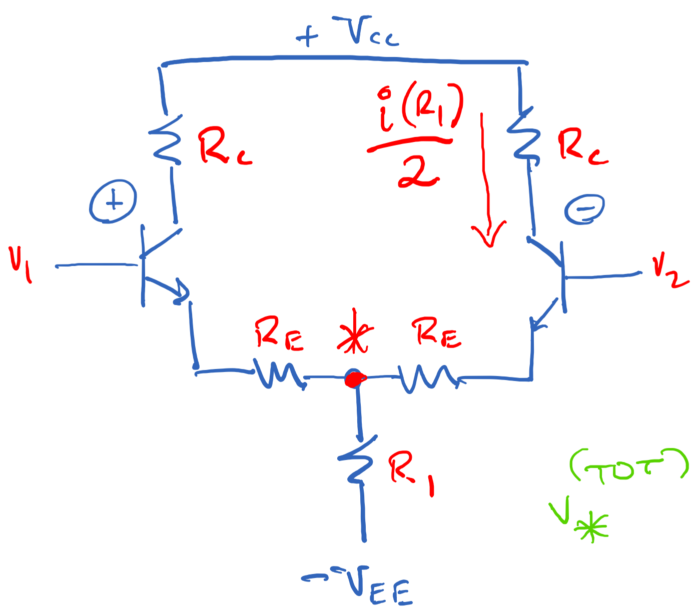
$$i_E \approx i_C = \frac{V_D}{2R_E}$$

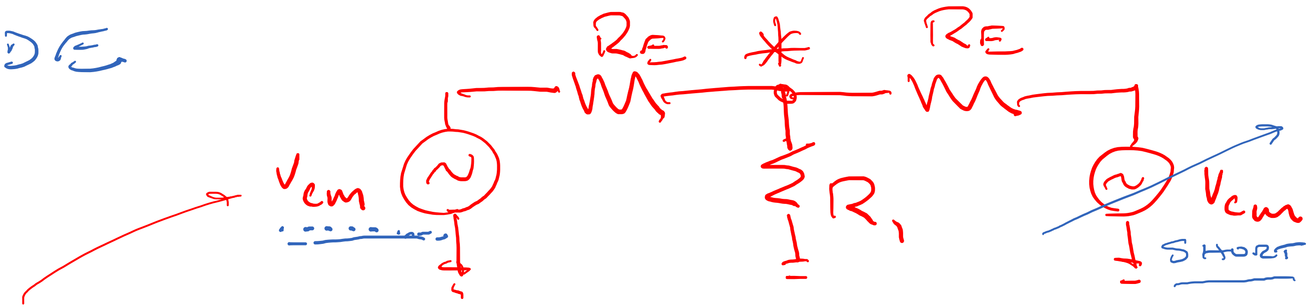
($\beta \gg 1$)

$$V_{out} = \frac{R_C}{2R_E} V_D \quad ; \quad \boxed{A_D = R_C / 2R_E}$$

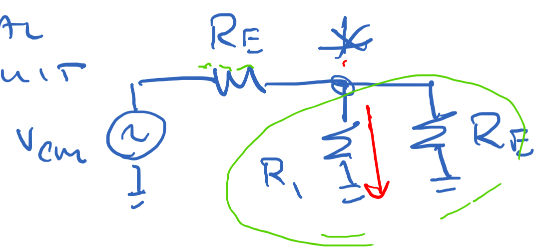
Common Mode

$V_1 = V_2 = V_{cm}$





PARTIAL CIRCUIT



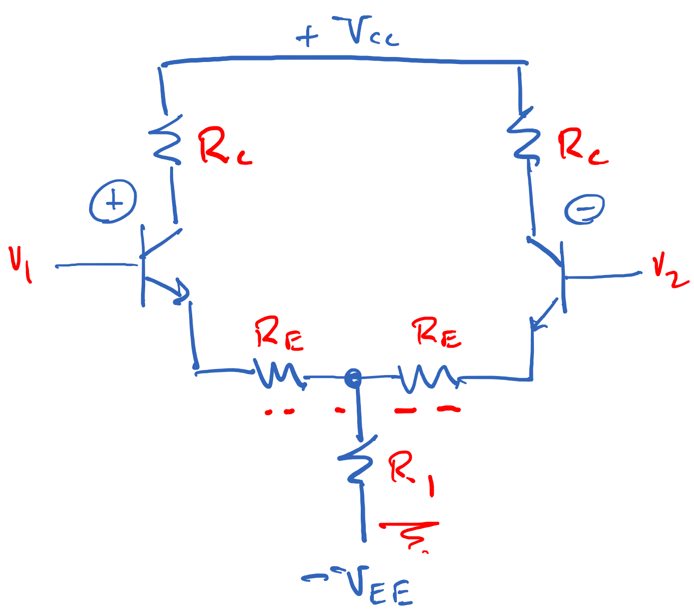
$$V_*^{(1)} = \frac{\frac{R_E R_1}{R_1 + R_E}}{\frac{R_E R_1}{R_1 + R_E} + R_E} \cdot V_{cm}$$

$$V_*^{(1)} = \frac{R_1}{R_E + 2R_1} V_{cm}$$

$$V_*^{(TOT)} = \frac{2R_1}{R_E + 2R_1} V_{cm} \; ; \quad i(R_1) = \frac{2}{R_E + 2R_1} \cdot V_{cm}$$

$$V_{out} = \frac{-R_c}{2R_1 + R_E} V_{cm} \; ; \quad A_{cm} = \frac{-R_c}{2R_1 + R_E}$$

Common-Mode Rejection Ratio



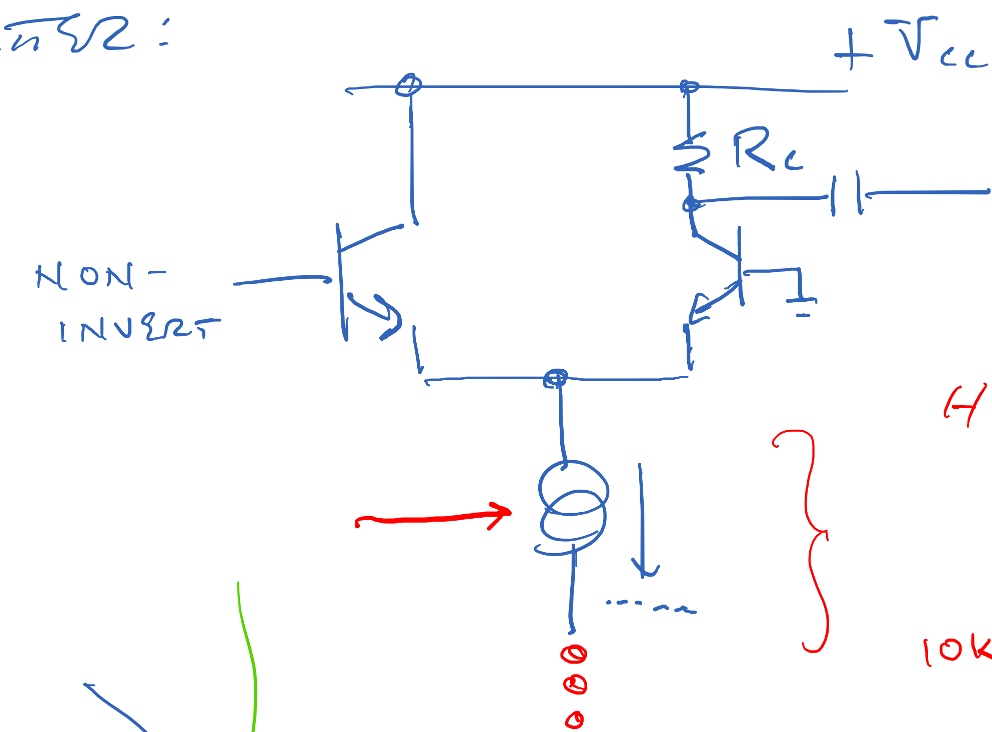
$$A_D = \frac{R_C}{2R_E}$$

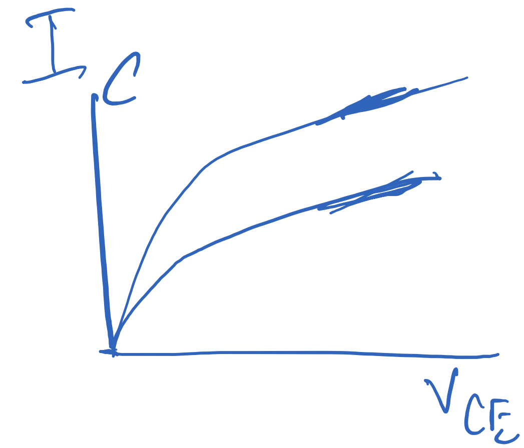
$$A_{cm} = \frac{-R_C}{2R_1 + R_E}$$

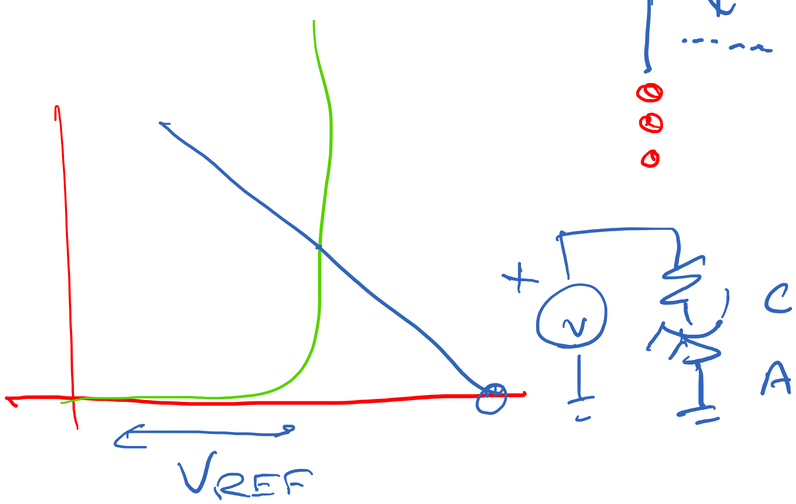
$$CMRR = \left| \frac{A_D}{A_{cm}} \right| = \frac{2R_1 + R_E}{2R_E}$$

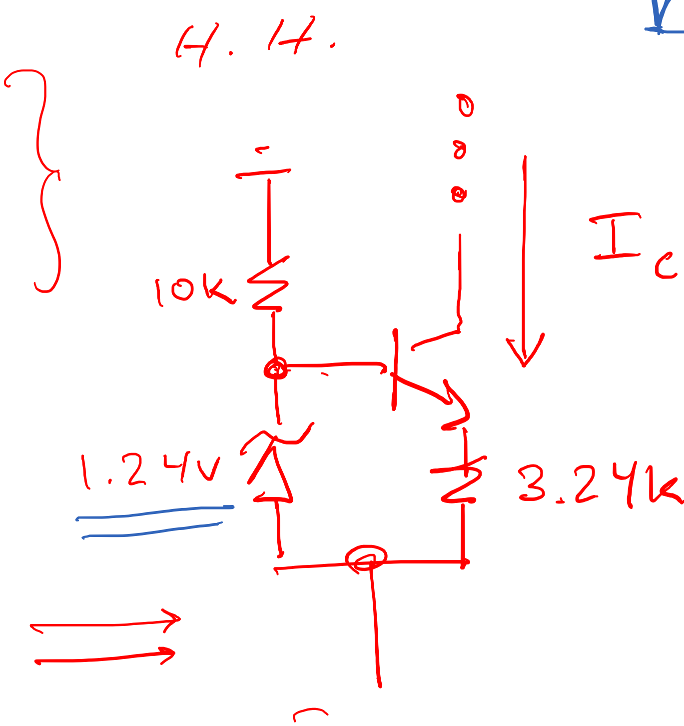
$$R_1 >> R_E \qquad \approx \frac{R_1}{R_E}$$

BETTER:





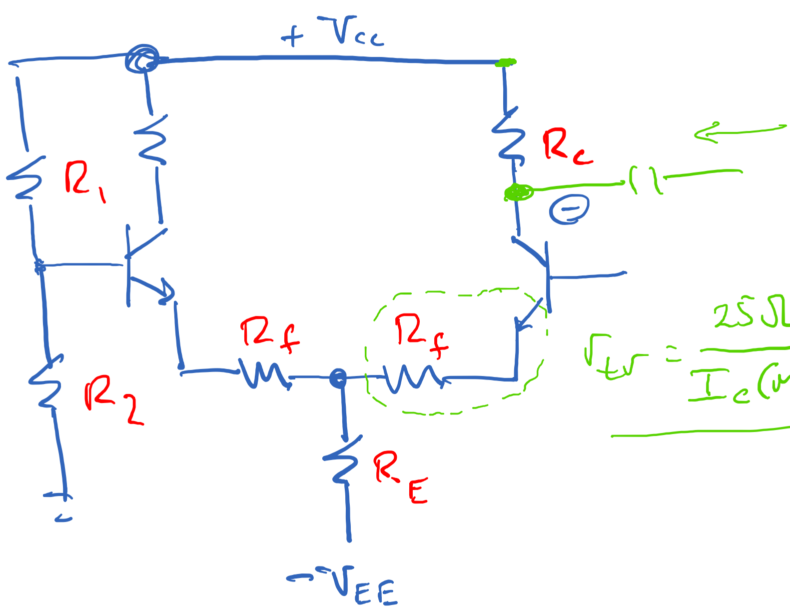




$$I_C = \frac{0.64\,V}{3.24\,k\Omega}$$

$$\sim 200\,\mu A.$$

DIFF AMP DESIGN



① $R_{out} = 1\,k\Omega \Rightarrow$

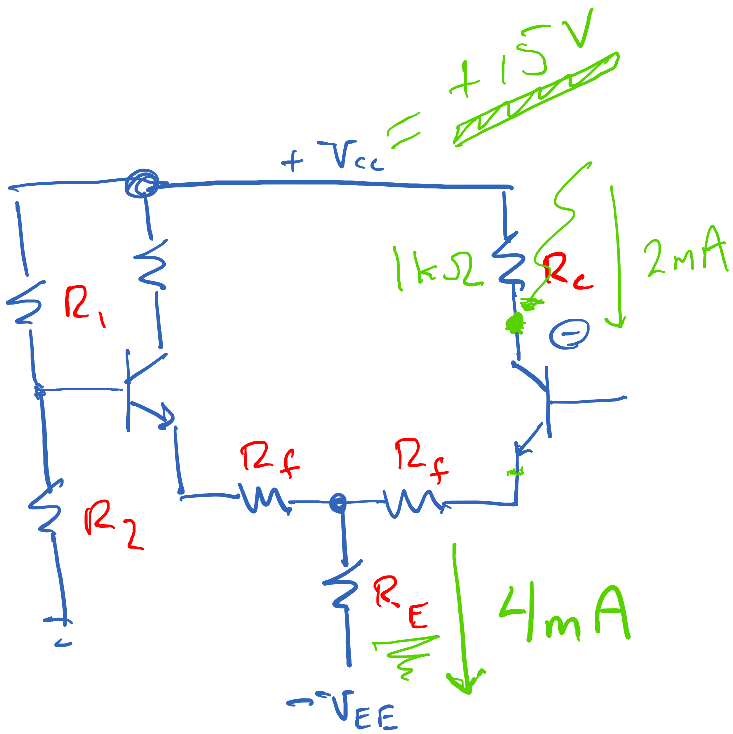
$R_c = 1\,k\Omega.$

② $A_D = 8 = \dfrac{R_c}{2(R_f + r_{tr})}$

$r_{tr} = \dfrac{25\,\Omega}{I_c(mA)} + 2\,\Omega$

$\Rightarrow R_f + r_{tr} = 62.5\,\Omega.$

DIFF AMP DESIGN



(3) OUTPUT SWING ±2 V

V_c LIMITED ABOVE BY $+V_{cc}$

V_c LIMITED BELOW BY CONSTRAINT

$V_{CE} \geq 0.5V$

$V_c \to 13$ V

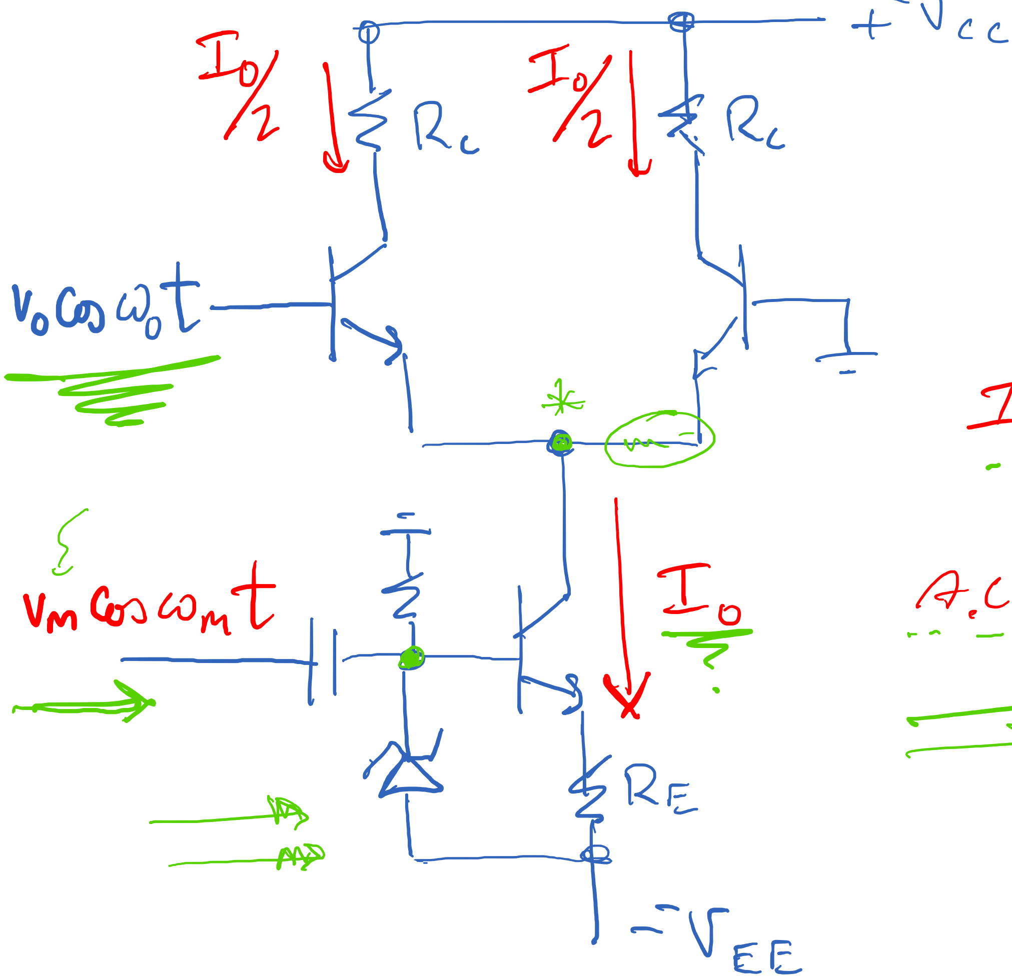
$I_c = 2$ mA

(4) WHAT COMMON MODE INPUT CAN YOU TOLERATE?

±2.5V COMMON MODE.

LIMIT ON $V_E \to 8$ V

GILBERT CELL MIXER



$$A_D = \frac{R_C}{2 r_{tr}} \; ; \quad r_{tr} = \frac{25}{I_C(mA)}$$

$$A_D \simeq \frac{R_C}{100} I_0(mA)$$

$$I_0 = I_0(DC) + \frac{V_m \cos \omega_m t}{R_E}$$

A.C. CONTRIBUTION TO A_D:

$$\Longrightarrow 0.1 \frac{R_C}{R_E} V_m \cos \omega_m t$$

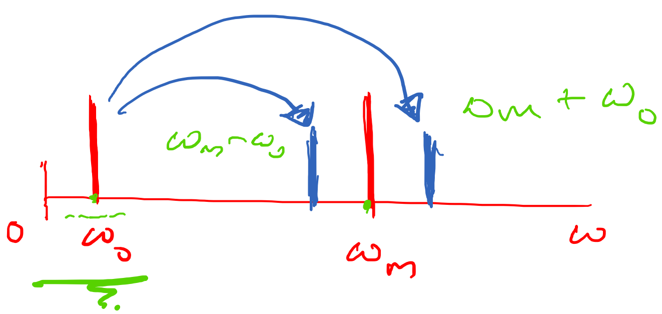
EXPRESSED IN VOLTS

V_{out} CONTAINS TERMS LIKE

$$(\cos\omega_0 t)(\cos\omega_m t)$$

$$= \frac{1}{2}\left\{\cos\left[(\omega_m+\omega_0)t\right] + \cos\left[(\omega_m-\omega_0)t\right]\right\}$$

UPCONVERSION



DOWNCONVERSION