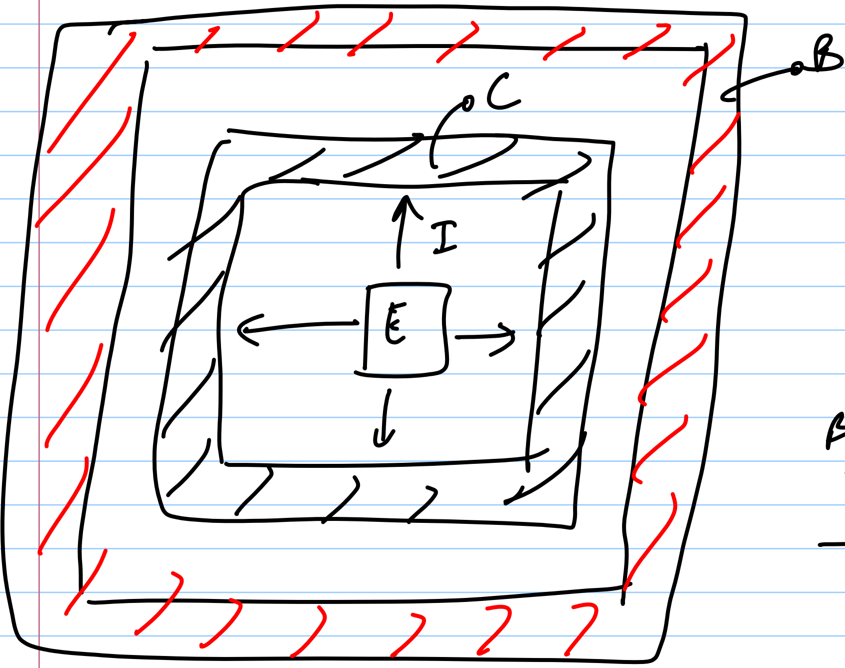
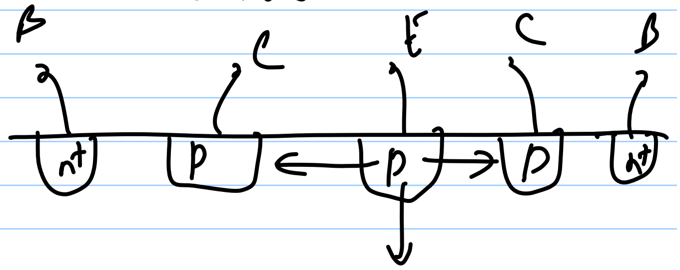
15-3-12

Lec 29

lateral pnp layout



'donut' layout
⇒ larger β
only vertical component of I_E is lost



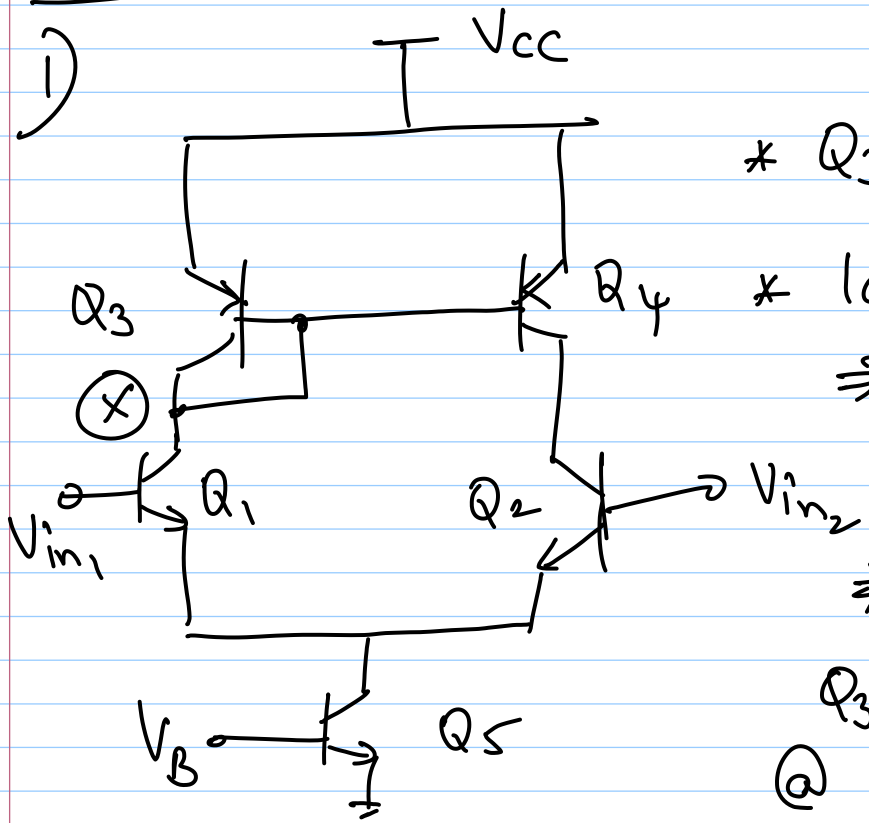
741 opamp

* stand-alone opamp
* internally compensated
* simple ckt, small area
* large gain, good CM & DM voltage ranges
* Dual supply ($+V_{CC}$, $-V_{EE}$)
* Differential input, SE o/p
* high R_{in}

* gain in input stage
  → noise & offset voltage of later stages is reduced
* large gain from second stage
* output stage that can drive large loads (low R_{out})

Evolution of 741 Input stage

1)

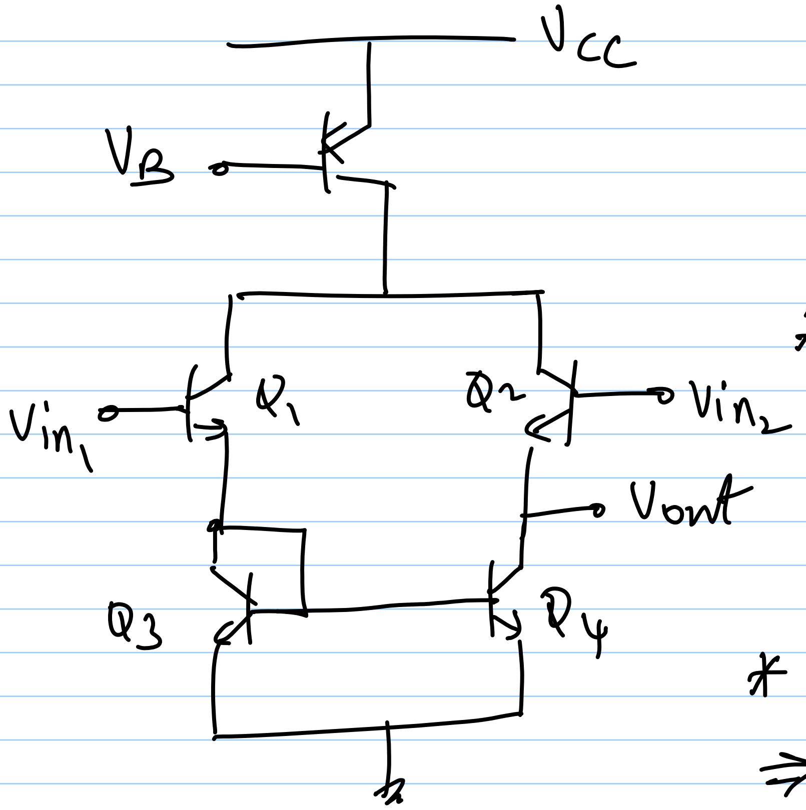


* Q_3, Q_4 – diff. to SE
* lat. pnp's are slow
  ⇒ $C_B = \tau_F \cdot g_m$ is large
  ⇒ $C_{B3} + C_{B4}$ causes Q_3, Q_4 to be slow @ node X.

key point

* pnp
  - o/c for dc bias & dc level shifting
  - too slow for use in signal path (CE config.)

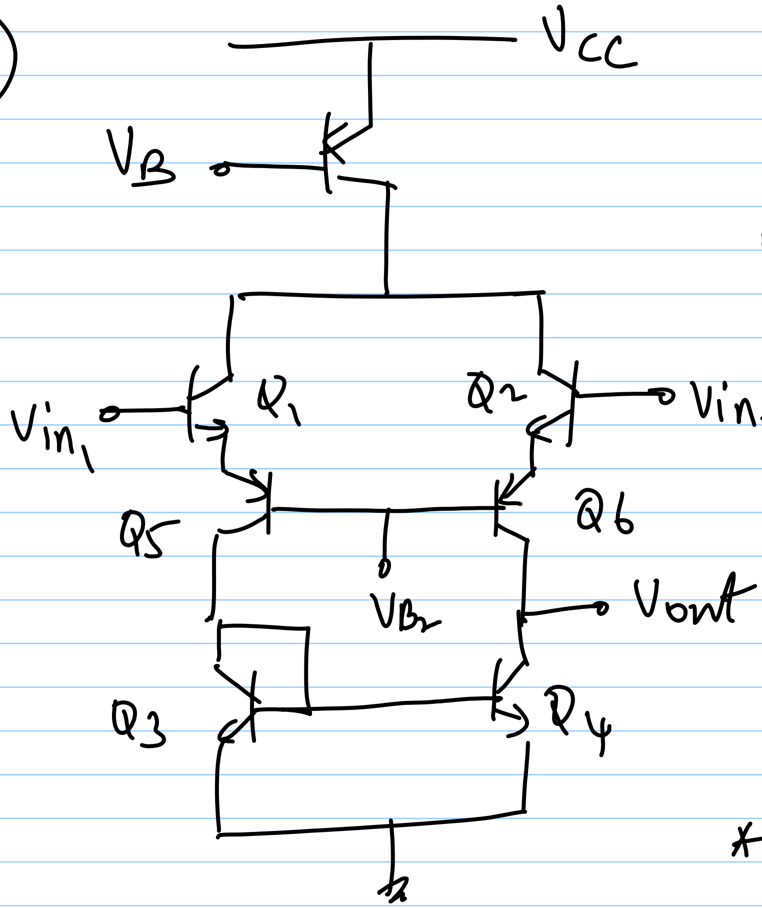
2) Use npn inputs & npn mirror stages



* all devices in signal path are npn
* $V_{in_1} = V_{BE_3} + V_{BE_1}$
  $\simeq 1.4V$
  - no input CM range!
* r_{out} = low

$\Rightarrow$ gain = low

3)



* Use pnp in CB config
* r_{out} is higher
  ⇒ higher gain
* $V_{in_1} = V_{B_2} + V_{EB5} + V_{BE_1}$
  ⇒ still zero i/p CM range
* high R_{in}, low I_{in}

4) <u>Don't fix V_{B_2}</u>

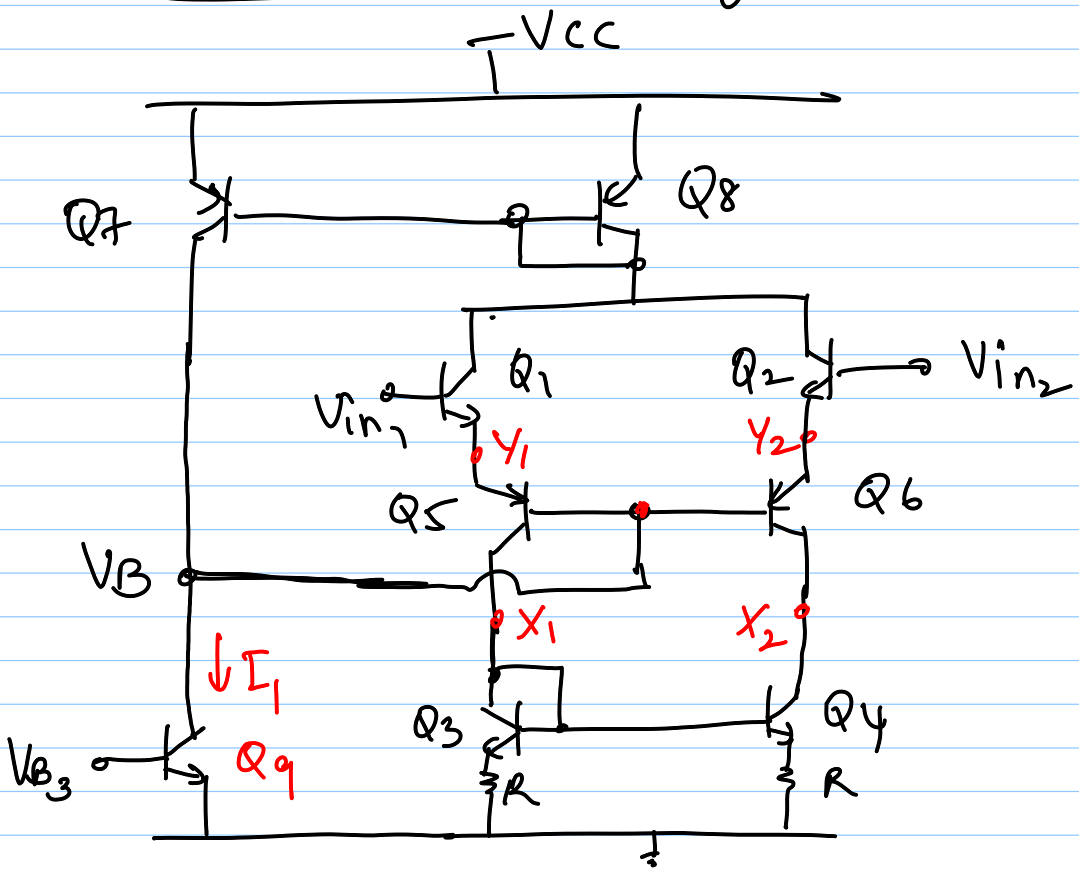
let V_{B_2} float w.r.t. V_{icm}

→ design so that

$$V_{B2} = V_{ic} - V_{BE_1} - V_{EB_5}$$

⇒ indirect biasing scheme

741 input stage

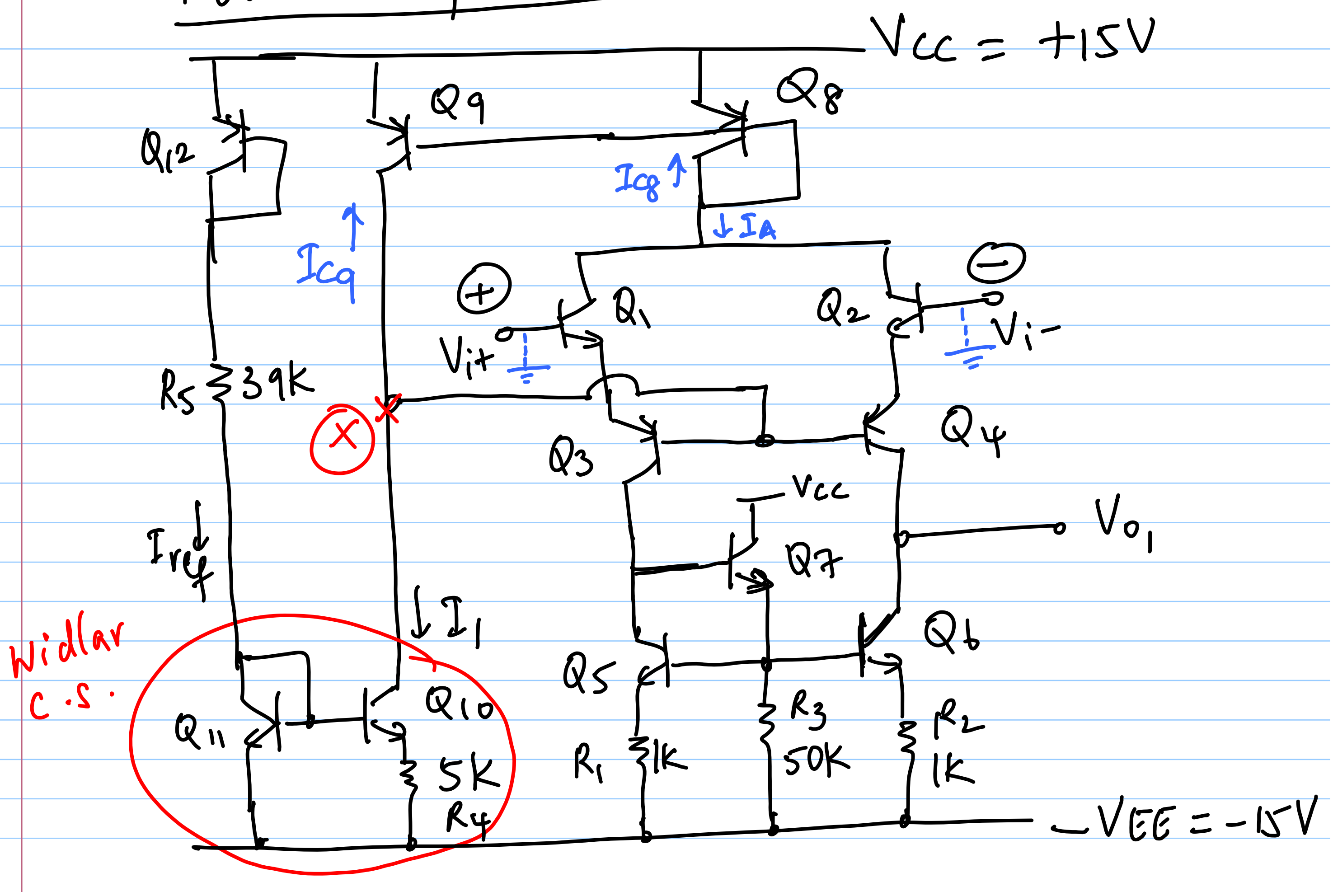


* f.b. loop around Q7 – Q8 – Q9 & input Q_{1-2}, Q_{5-6} will automatically adjust V_B so that $I_7 = I_8 = I_1$ (neglecting base current errors)
* degeneration resistors improve R_{out} for higher gain & improve $Q_3 - Q_4$ matching

Other details

* β-helper for CM load improves mirroring
* $Q_5 - Q_6$ provide DC level shifting
  → Emitters (Y_1, Y_2) are near V_{in}
  → Collectors (X_1, X_2) are near $-V_{EE}$
* Generate bias current using Widlar source

Full input stage



DC Analysis

* Assume that ckt is in f.b. so that overall $V_{out} = 0$
* neglect Early effect for DC
* assume $\beta_{dc,npn}$ is large but $\beta_{dc,pnp}$ is not
* neglect npn I_B's, but not pnp I_B's
* assume all devices in FAR

1) $I_{ref} = \dfrac{V_{CC} + V_{EE} - V_{EB12}(ON) - V_{BE11}(ON)}{R_5}$

$\approx \dfrac{30 - 1.4}{39K} = \boxed{733\mu A}$

2) large $\beta_{npn} \Rightarrow I_{C10} \approx I_{E10} \approx I_1$

$V_{BE11} - V_{BE10} - I_{E10} R_4 = 0$

$V_T \ln \dfrac{I_{ref}}{I_1} = I_1 R_4$

iteration : $\boxed{I_1 = 19\mu A}$

3) $I_A = -I_{cq}\left(1+\frac{2}{\beta_{pnp}}\right)$ —— 1

$$\left.\begin{array}{l} I_{C_1} = I_{E_1} \\ I_{C_2} = I_{E_2} \end{array}\right) \quad \beta_{npn} \text{ is large}$$

$$\Rightarrow I_A = I_{C_1} + I_{C_2} = I_{E_1} + I_{E_2}$$

$$= I_{E_3} + I_{E_4} = -I_{cq}\left(1+\frac{2}{\beta_{pnp}}\right)$$

KCL @ X : $I_{cq} + I_1 = I_{B_3} + I_{B_4}$

$$\Rightarrow 19\mu A = -I_{cq} + \frac{1}{1+\beta_{pnp}}\left(I_{E_3} + I_{E_4}\right)$$

$$19\mu A = -I_{cq} + \frac{1}{\beta_{pnp}+1} \cdot \left[-I_{cq} \cdot \left(1+\frac{2}{\beta_{pnp}}\right)\right]$$

$$19\mu A = -I_{cq}\left[1 + \frac{1+2/\beta_{pnp}}{1+\beta_{pnp}}\right]$$

$$-I_{cq} = \frac{19\mu A}{\left[1 + \frac{1+2/\beta_{pnp}}{1+\beta_{pnp}}\right]} \quad \text{—— 2}$$

2 in 1

$$\Rightarrow I_A = -I_{cq} \cdot \left(1 + \frac{2}{\beta_{pnp}}\right)$$

$$I_A = \frac{.19\mu A}{\left[1 + \frac{(1 + 2/\beta_{pnp})}{(1+\beta_{pnp})}\right]} \cdot (1 + 2/\beta_{pnp})$$

$$\approx 19\mu A \cdot \left(1 + \frac{1}{\beta_{pnp}}\right)$$

Finally,

$$I_{C3} + I_{C4} = \frac{(I_{E3} + I_{E4})}{\beta_{pnp} + 1} \cdot \beta_{pnp}$$

$$\approx \frac{I_A \cdot \beta_{pnp}}{1 + \beta_{pnp}} \approx +19\mu A$$

$\Rightarrow$ $I_{C3} + I_{C4}$ is insensitive to β_{pnp} due to biasing method

* This is an example of <u>common mode negative feedback</u>