Lecture 21 : Gilbert Mixers

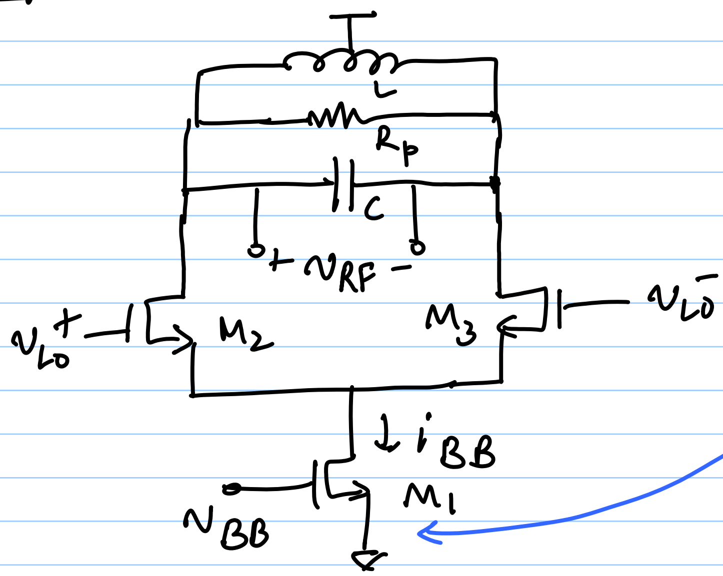
Conversion gain (v_{RF} to i_{out})

* $a_c = \frac{2}{\pi} \cdot g_m$
  - → assume LO devices are perfect switches
  - → IF signal is divided between $\omega_{LO} \pm \omega_{RF}$ freq.

Mixer load

* Filtering for LO, harmonics
* T_x → LC load
  R_x → RC load for Homodyne
  RC/LC load for heterodyne

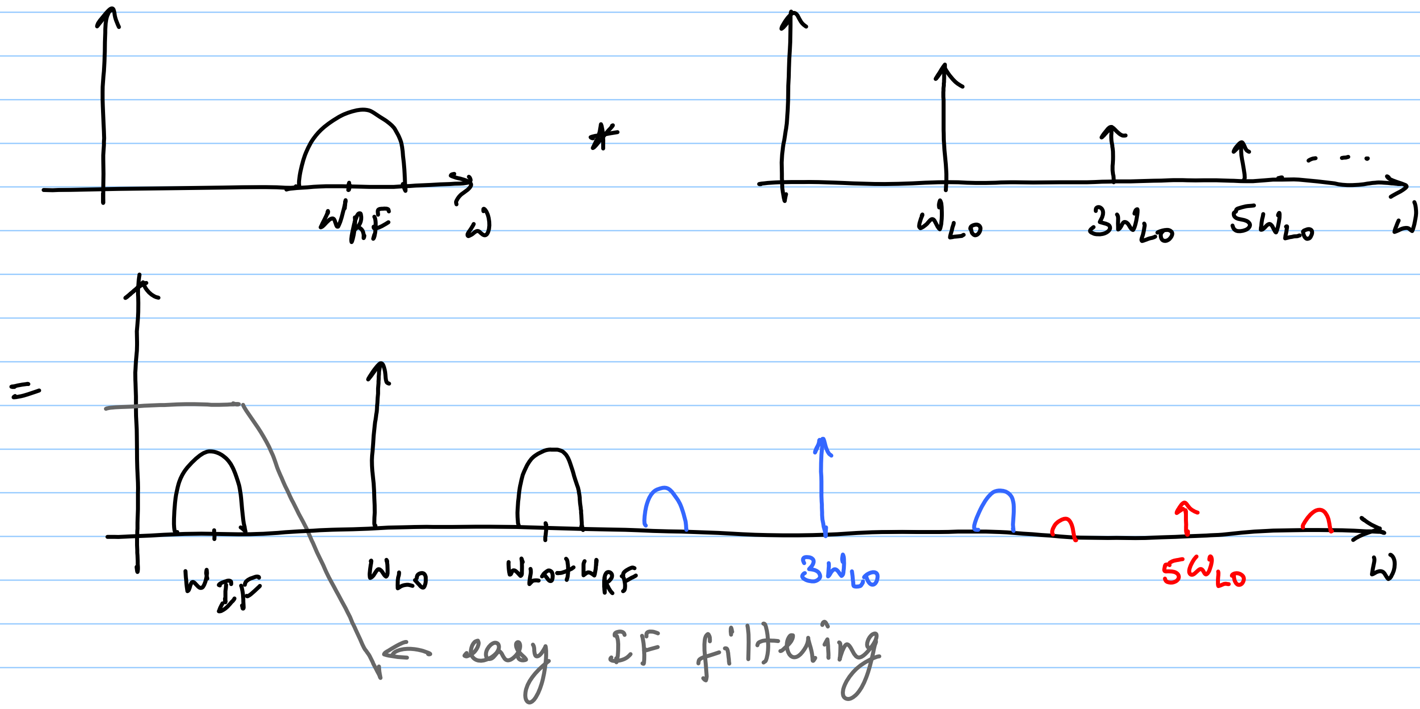
Up-conversion mixer could look like!

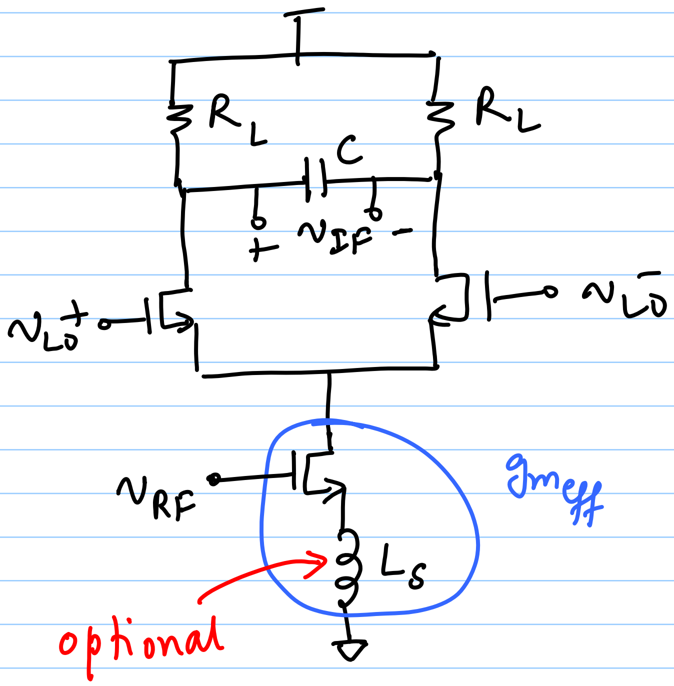


* LC tank load
* R_p = resistance of tank @ resonance
* can use R_E degeneration if headroom permits

* Conversion gain (v_{BB} to v_{RF}) $= \frac{2}{\pi} g_m R_p$
* $\omega_{RF} = \omega_{LO} + \omega_{BB}$

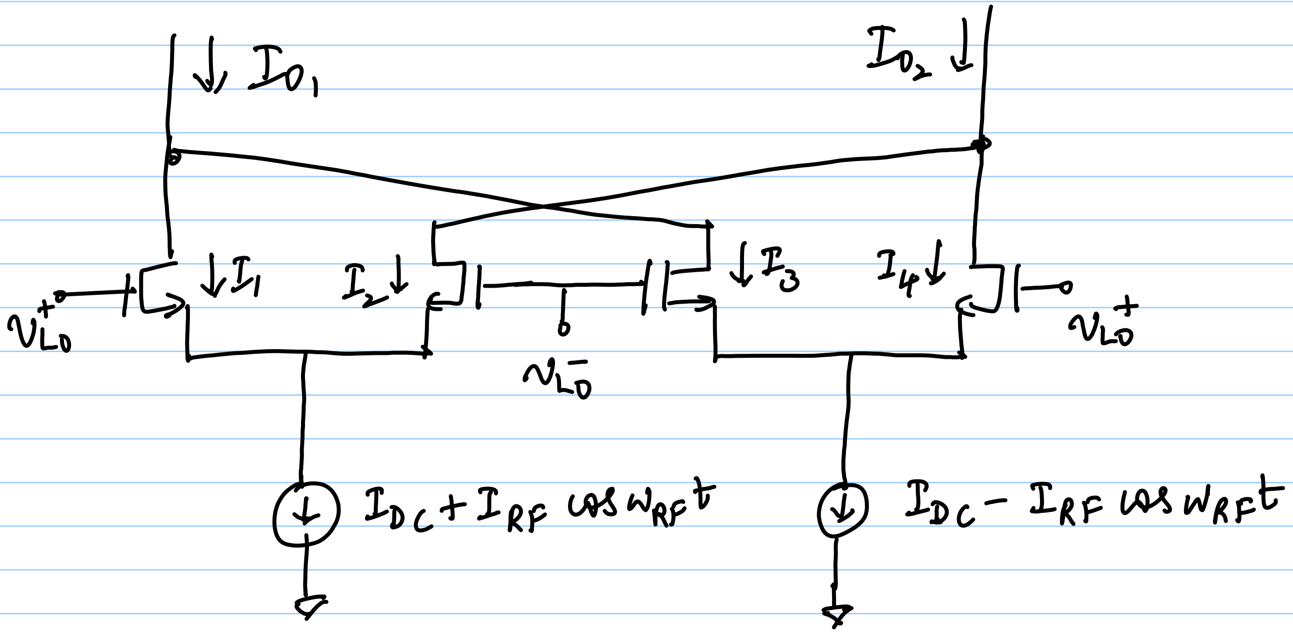
Down-conversion mixer: $\omega_{LO} - \omega_{RF} = \omega_{IF}$





* RC load – low pass response to eliminate higher harmonics i.e. LO-IF isolation not a major issue
* $G_c = \frac{2}{\pi} g_{m_{eff}} R_L$

Double-balanced mixer:



$$I_1 - I_2 = (I_{DC} + I_{RF}\cos\omega_{RF}t)\cdot s(t)$$

$$I_4 - I_3 = (I_{DC} - I_{RF}\cos\omega_{RF}t)\cdot s(t)$$

{note v_{LO}^{+} & v_{LO}^{-} connections relative to I_3, I_4}

$$I_{O_1} = I_1 + I_3$$

$$I_{O_2} = I_2 + I_4$$

$$I_{out} = I_{O_1} - I_{O_2}$$ {differential current}

$$= (I_1 + I_3) - (I_2 + I_4)$$

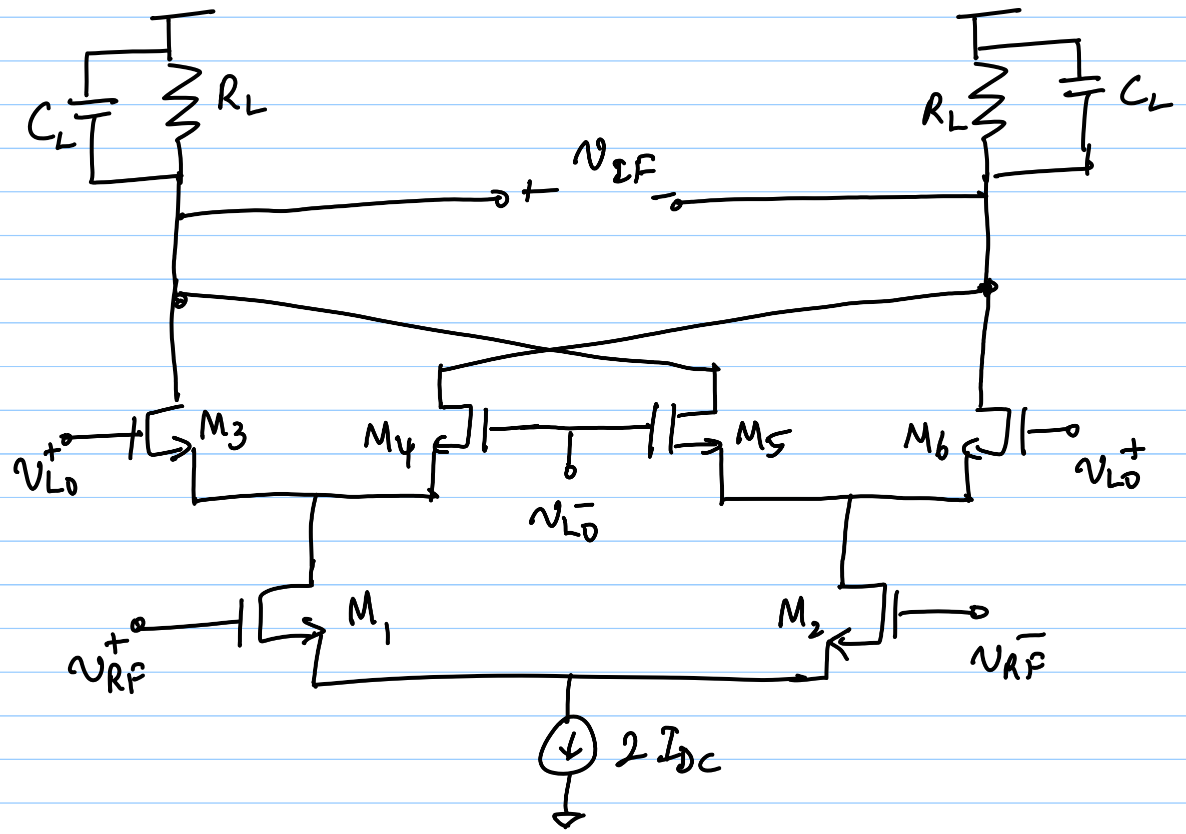
$$= (I_1 - I_2) - (I_4 - I_3)$$

$$= [2 I_{RF}\cos\omega_{RF}t]\cdot s(t)$$

$$= \frac{4}{\pi} I_{RF}\Big[\sin(\omega_{LO} - \omega_{RF})t + \sin(\omega_{LO} + \omega_{RF})t + \frac{1}{3}\sin(3\omega_{LO} - \omega_{RF})t + \frac{1}{3}\sin(3\omega_{LO} + \omega_{RF})t + \cdots\Big]$$

⇒ excellent LO-IF isolation (but depends on matching between differential paths)

Gilbert-cell mixer: (Rx)



* conversion gain

$$G_c = \frac{\text{amplitude of IF output}}{\text{amplitude of RF input}}$$

$$= \frac{\frac{4}{\pi} I_{RF} \cdot R_L}{2v_{RF}} = \frac{2}{\pi} g_m R_L$$

* Good LO-IF isolation ⟺ matching (M_1-M_2 & M_3-M_4-M_5-M_6)

1% matching ⇒ 40dB isolation

0.1% matching ⇒ 60dB isolation

possible with careful analog layout techniques

sources of mismatch: $\Delta W, \Delta L$, ΔV_T, C_{ox}

photolithography → $\Delta W, \Delta L$

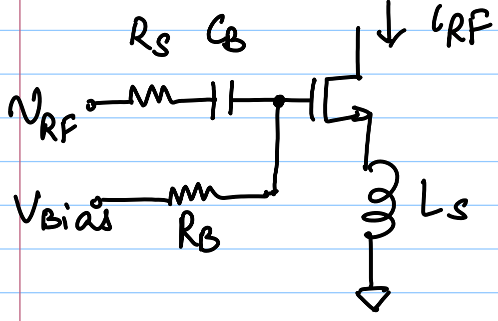
ΔV_T ← N_a, t_{ox}, ϵ_{ox}

C_{ox} ← t_{ox}, ϵ_{ox}

RF transconductors

(A) common source:

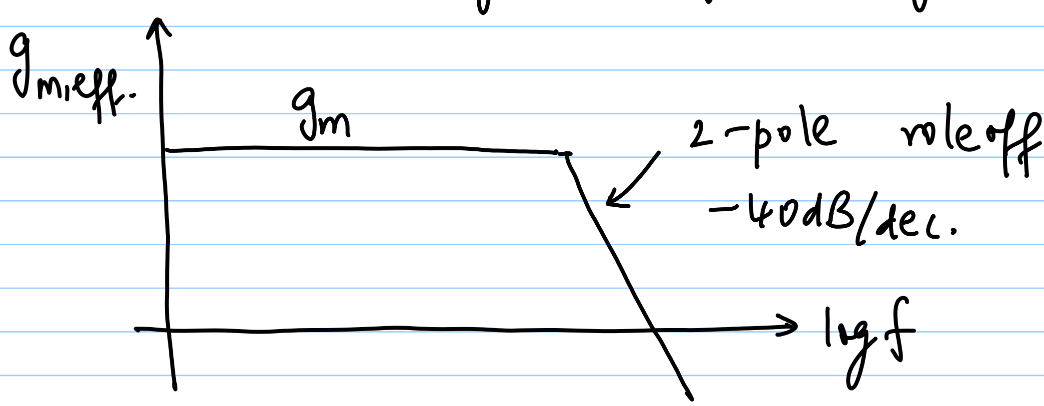
* linearity enhanced through source degeneration



* L_S:
  - → no thermal noise
  - → no DC drop (extra headroom)
  - → $|Z_L| = \omega L_S$ helps attenuate high-frequency harmonic & IM components

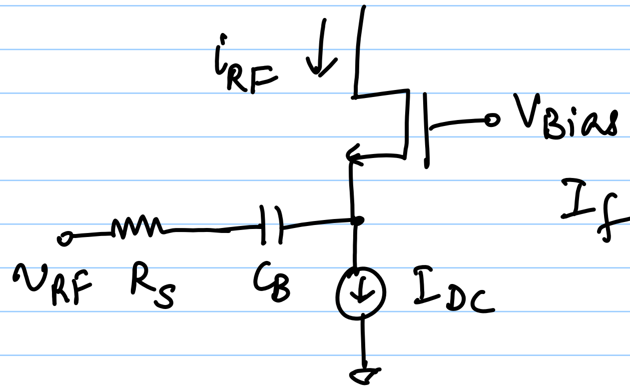
* V_{Bias} → sets I_{DC}
* R_B = large
  - → reduce loading on v_{RF}
  - → reduce noise

$$g_{m,eff.} = \frac{g_m}{s^2 L_s C_{gs} + s(g_m L_s + C_{gs} R_s) + 1}$$



* good attenuation of high-freq. content (2-pole rolloff)
* Careful about $\omega_T L_S$ portion of Z_{in} – could de-Q LNA drain LC tank

(B) common-gate:

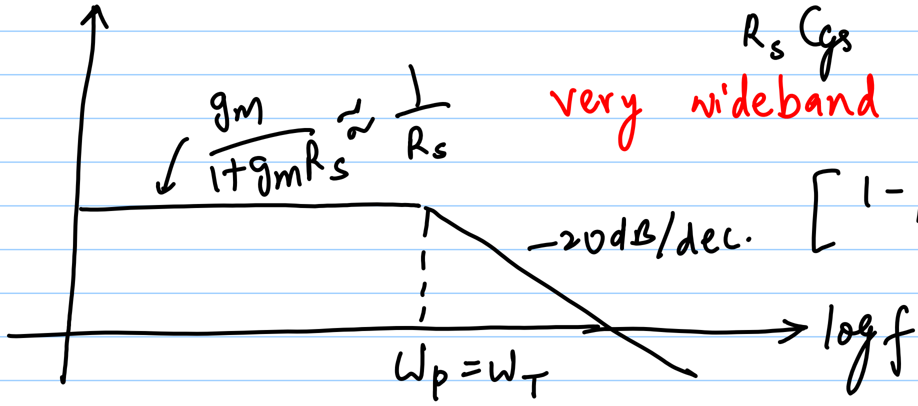


$$g_{m,eff.} = \frac{g_m}{1 + g_m R_s + s R_s C_{gs}}$$

If $g_m \gg \frac{1}{R_s}$, $\boxed{g_{m_{eff.}} \approx \frac{1}{R_s}}$

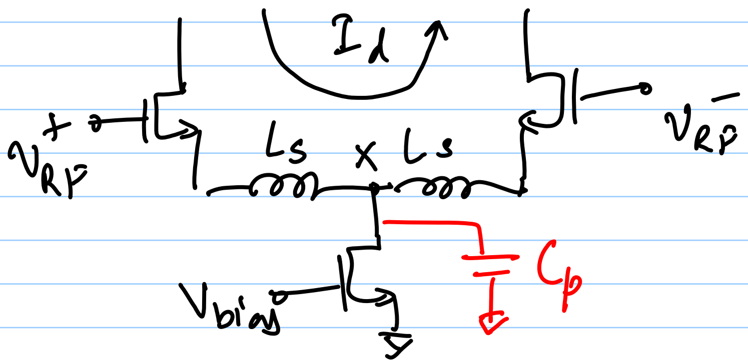
$$\omega_p = \frac{1 + g_m R_s}{R_s C_{gs}} \approx \frac{g_m}{C_{gs}} = \underline{\underline{\omega_T}}$$

very wideband transconductor!



[1-pole roll-off @ high freq.]

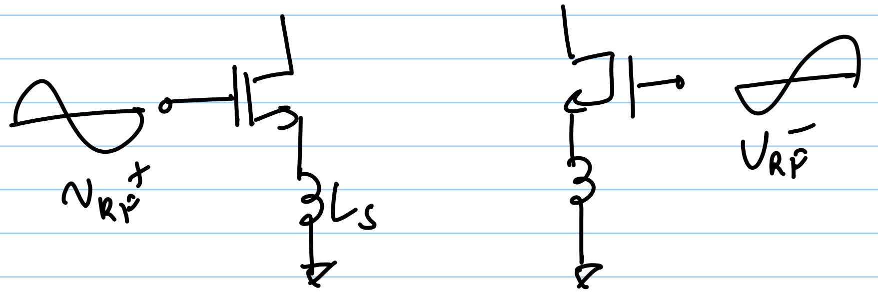
(C) Differential transconductor



* fully differential
* L_s optional
* good CMRR @ low freq.

* C_p limits high-freq. CMRR
* no even harmonics {matched}
* significant 3rd order nonlinearity – IM_3
* tail current source uses up headroom
* Node X voltage has even order harmonics

(D) Balanced CS transconductor (pseudo-differential)



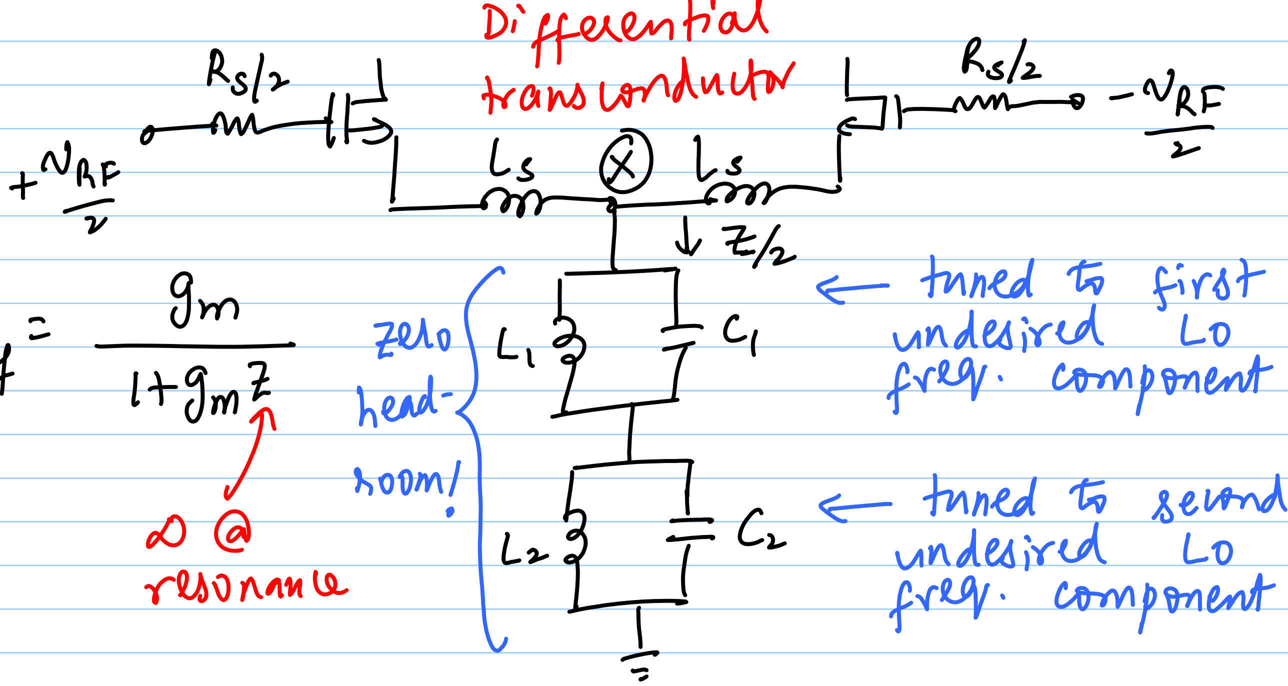
* best voltage headroom

* No current source ⇒ CMRR = 0 for all freq.
* CMRR is obtained through perfect balance
* Long-channel assumption

$$I_d = \frac{k_n'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2 \Rightarrow \text{no third order component}$$

⇒ excellent IIP3

* harmonic filtering: (widely used in PAs also)

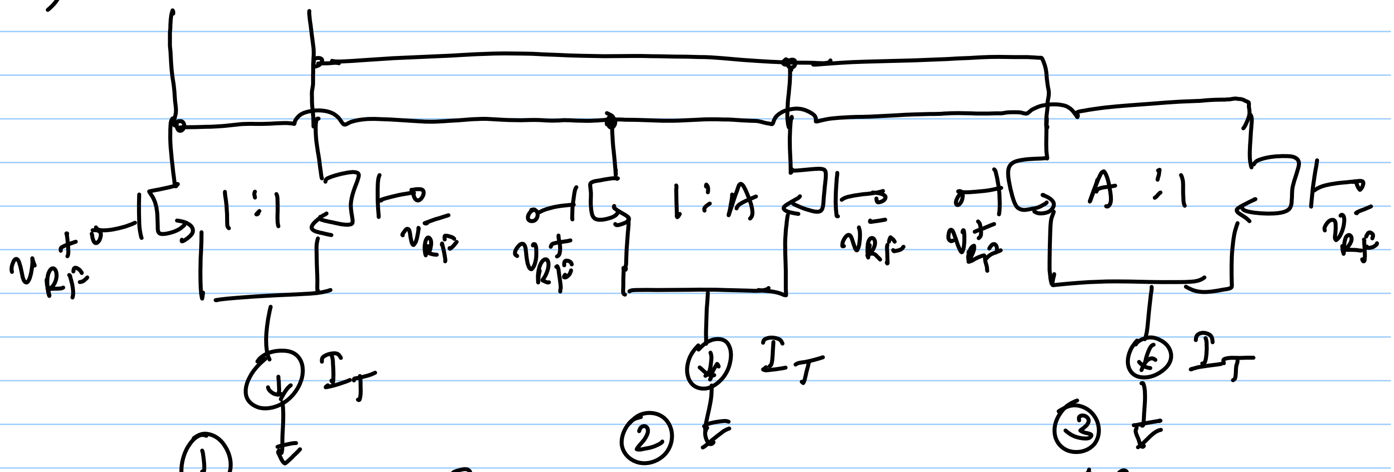


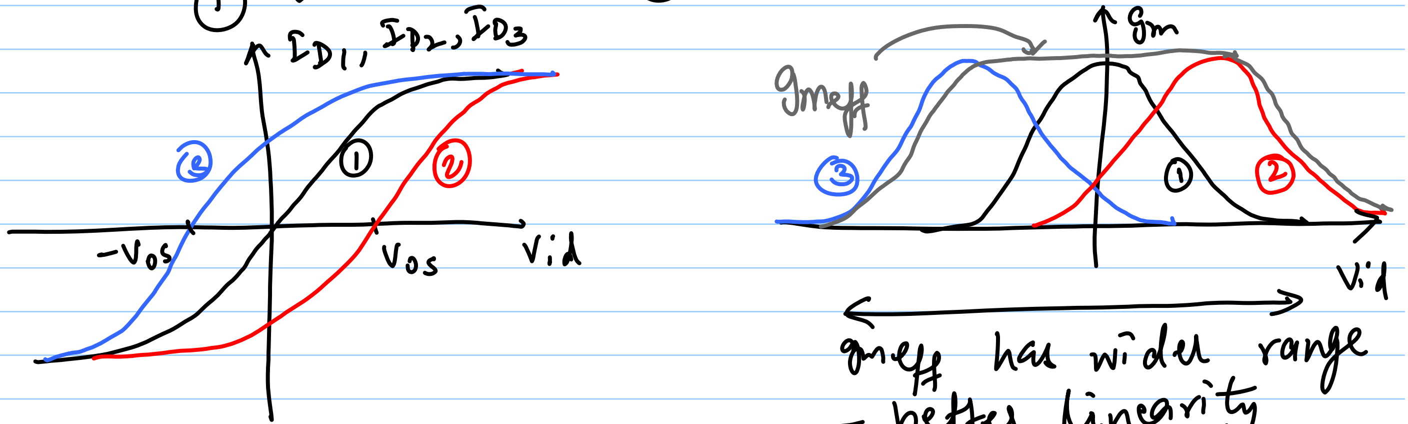
$$g_{m_{eff}} = \frac{g_m}{1+g_m Z}$$

(Z ⟶) ∞ @ resonance

* node x voltage has even order harmonics
  ⇒ use L_1–C_1 etc. to create high-Z

(E) "Multi-tanh" transconductor





g_{meff} has wider range
– better linearity