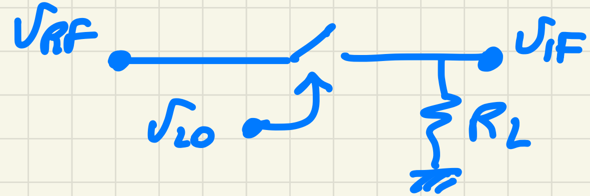
RF Circuit Design

L20

Input-referred noise



$$PSD_{v_{RF}} = \frac{PSD_{v_{IFn}}}{A_v^2}$$

$$A_v = \frac{1}{\pi} \frac{R_L}{R_L + r_{on}}$$

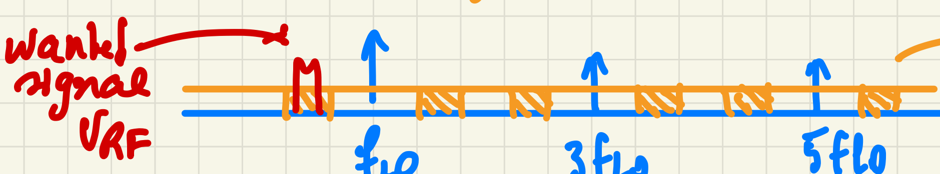
$2kT(r_{on} \| R_L)$
$+ 2kTR_L$

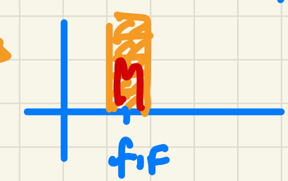
minimize $PSD_{v_{RF}} = \underbrace{117}_{} \cdot kT \cdot r_{on}$

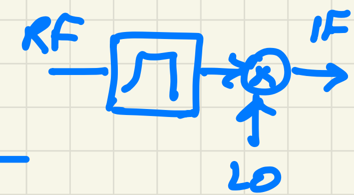
for $R_L = \sqrt{2} \cdot r_{on}$

mixer noise is typically considerablly larger than source noise

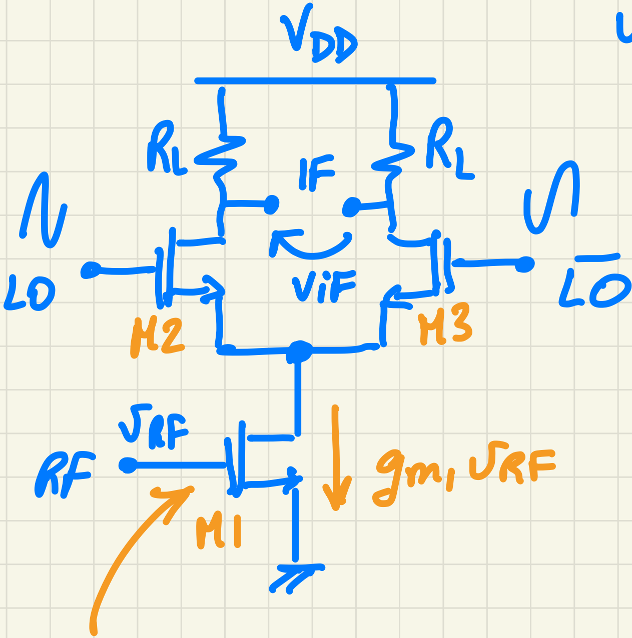
→ noise figure contribution is relevant







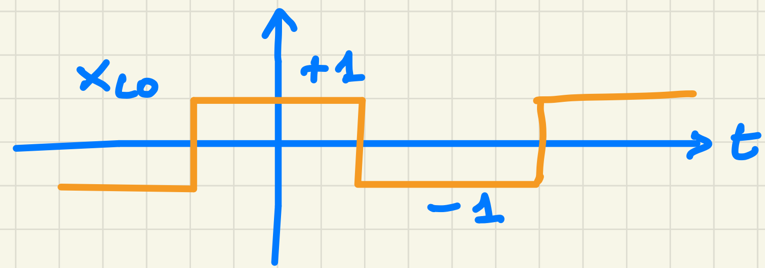
Active mixers



transconductor

LTV model

$$v_{IF}(t) = g_{m1}\, v_{RF}(t) \cdot \underbrace{x_{LO}(t)}_{} \cdot R_L$$



Hyp
- full switching M2 / M3
- 50% duty cycle
- M1 is always in SAT

Conversion gain : $A_V = \dfrac{V_{IF}(\omega_{RF}-\omega_{LO})}{V_{RF}(\omega_{RF})}$

$$v_{RF}(t) = A \cos \omega_{RF} t$$

$$v_{IF}(t) = \overset{v_{RF}(\omega_{RF})}{g_{m1} R_L} \cdot \underline{A \cos \omega_{RF} t} \cdot \left(\frac{4}{\pi} \underline{\cos \omega_{LO} t} + \right.$$

* No DC component

$$\left. - \frac{4}{3\pi} \cos 3\omega_{LO} t + \ldots \right) =$$

$$= \underbrace{g_{m1} R_L \cdot A \cdot \frac{\cancel{4}^{2}}{\pi} \cdot \frac{1}{\cancel{2}}}_{v_{IF}(\omega_{RF} - \omega_{LO})} \cos(\omega_{RF} - \omega_{LO}) t + \text{o.t.}$$

$(\omega_{RF} + \omega_{LO})$
$(3\omega_{LO} - \omega_{RF})$
$(3\omega_{LO} + \omega_{RF})$

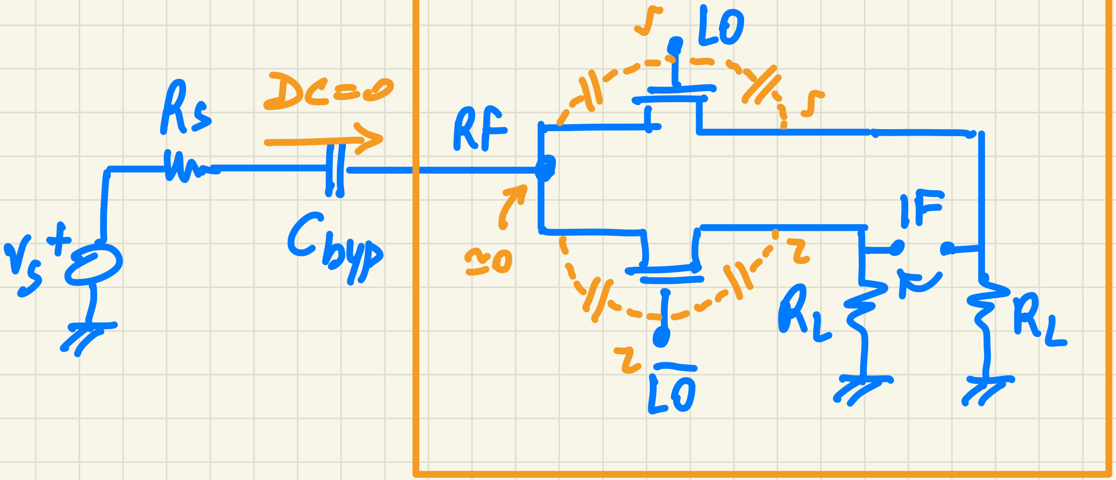
$\Downarrow$

- $A_v = \frac{2}{\pi} \cdot g_{m1} R_L$

- RF-to-IF feedthrough is ideally zero*

SINGLE-BALANCED mixer (LO signal is balanced)

** Passive Single - balanced mixer



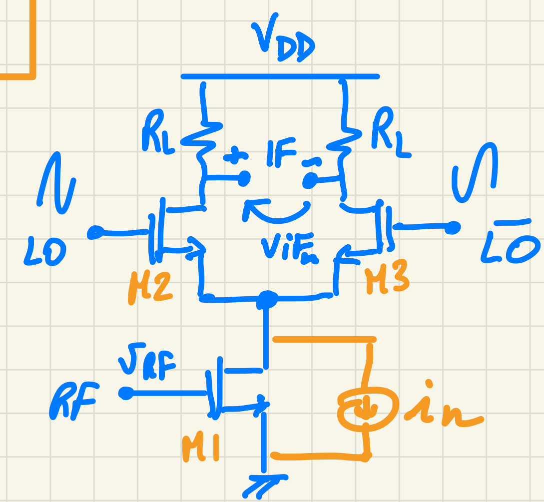
- $A_V = \frac{2}{\pi} \cdot \frac{R_L}{R_L + r_{on}}$
- zero RF-to-IF feedthrough
- zero LO-to-RF
- nonzero LO-to-IF

- Noise in active mixer :

$$PSD^{SSB}_{V_{IFn}}\Big|_{UNBAL} = 2 \times 4KTR_L + 4KT\frac{\gamma}{\alpha} g_{m1} R_L^2$$

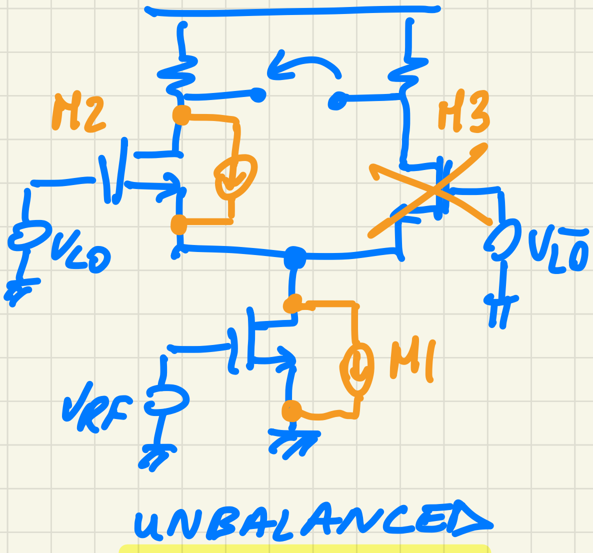
2resistors

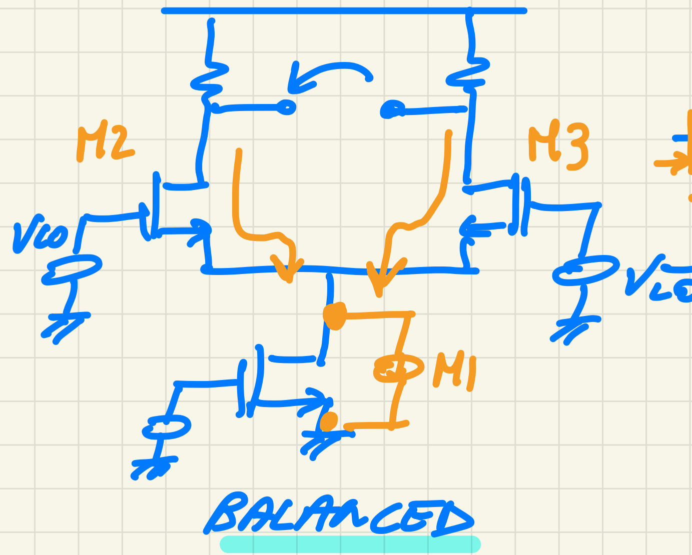
$V_{IFn} = R_L \cdot i_n(t) \cdot x_{LO}(t)$

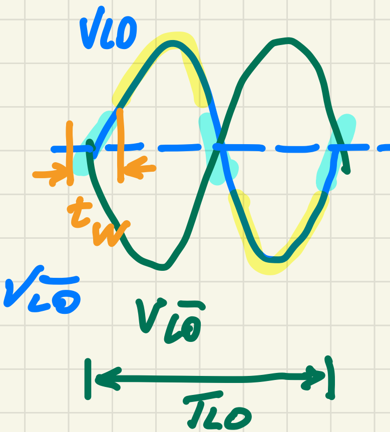


$$PSD^{DSB}_{M1} = R_L^2 \cdot \underbrace{2kT\frac{\gamma}{\alpha}g_{m1}}_{PSD^{DSB}_{in}} \cdot \underbrace{\sum |c_k|^2}_{\frac{1}{T}\int_0^T |x_{LO}(t)|^2 dt = 1} = 2kT\frac{\gamma}{\alpha}g_{m1}R_L^2$$

$PSD_{M2} = PSD_{M3} = 0$ because M2/M3 are cascoded







$$PSD\Big|_{V_{IF_n}}^{BAL} = \underbrace{8KTR_L}_{R_L} + \underbrace{8KT\frac{\gamma}{\alpha}\cdot g_{m2} R_L^2}_{M2+M3}$$

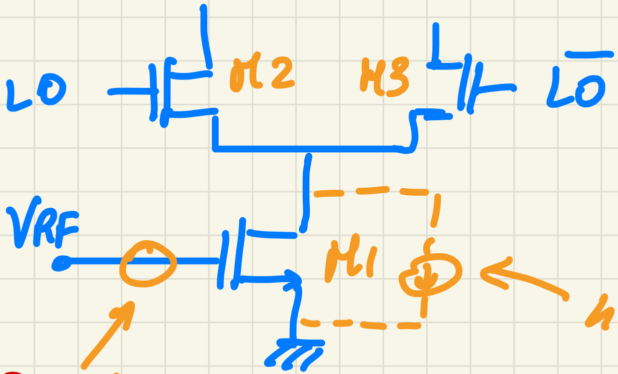
Hyp: abrupt switching $\quad PSD \simeq PSD\Big|^{UNBAL.}$

Hyp: low pass filtering at mixer output

$$\text{Average } PSD^{SSB} = PSD\Big|^{UNBAL}\cdot \underbrace{\left(1-\frac{2t_w}{T_{LO}}\right)}_{\text{Duty cycle of the unbalanced config.}}$$

$$+\ PSD\Big|^{BAL}\cdot \underbrace{\frac{2t_w}{T_{LO}}}_{\text{Duty cycle of BAL.}}$$

input referred mixer noise



$4kT\frac{\gamma}{\alpha}g_{m1}$ ⇒ V_{IFn} : $4kT\frac{\gamma}{\alpha}g_{m1}R_L^2$

$4kT\frac{\gamma}{\alpha}\frac{1}{g_{m1}}$

incorrect

input-refer

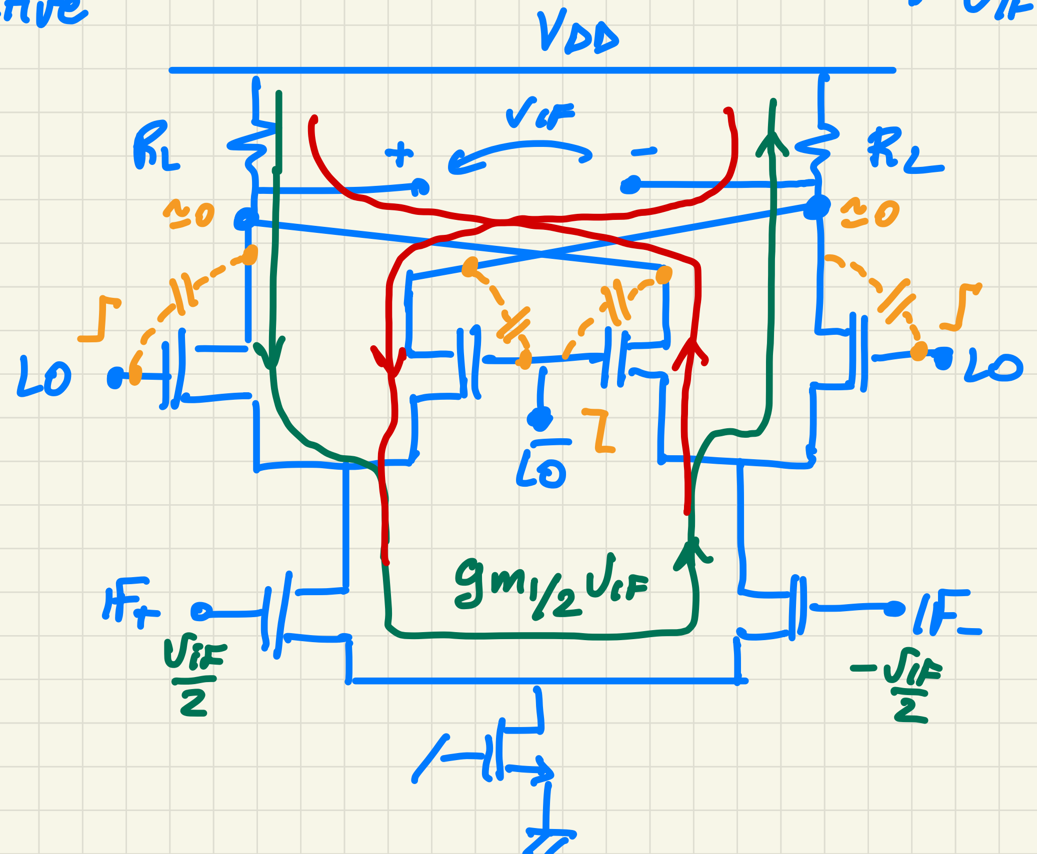
$$\frac{PSD\ V_{IFn}}{A_v^2} = \frac{\cancel{4}kT\gamma/\alpha\,\cancel{g_{m1}}\,\cancel{R_L^2}}{\left(\frac{\cancel{2}}{\pi}\right)^2 g_{m1}^{\cancel{2}}\,\cancel{R_L^2}} =$$

correct

$$= \pi^2 \cdot kT \cdot \frac{\gamma}{\alpha} \cdot \frac{1}{g_{m1}}$$

DOUBLE BALANCED mixers

Active



- $V_{IF}(t) = g_{m1} v_{IF} \cdot R_L \cdot x_{LO}(t)$

$\Downarrow$

$$A_v = \frac{2}{\pi} g_{m1} R_L$$

- zero LO-to-IF feedthrough (Relevant because LO is large signal)

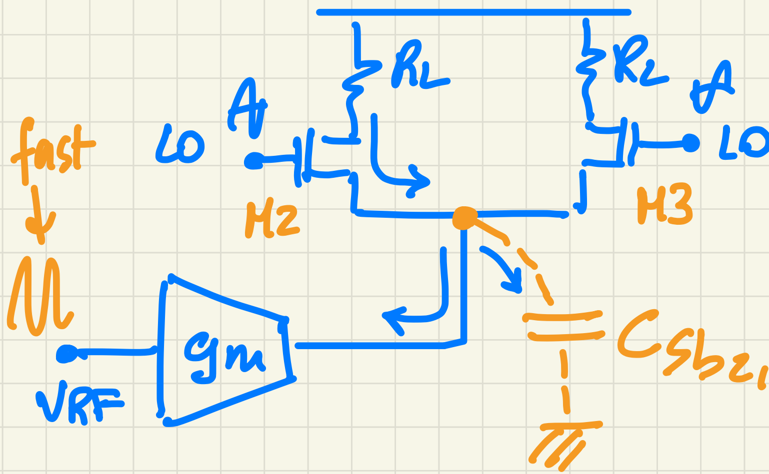
Both LO and IF are balanced signal

- linearity of active mixers → – linearity of gm stage

  – Current division between M2/M3 and C_{PAR}

  ↓

  nonlinearity if M2/M3 go to triode region



$C_{sb_{2,3}} + C_{db_1} + \dots = C_{PAR}$

→ M2/M3 always in satur.

↓

limit LO amplitude