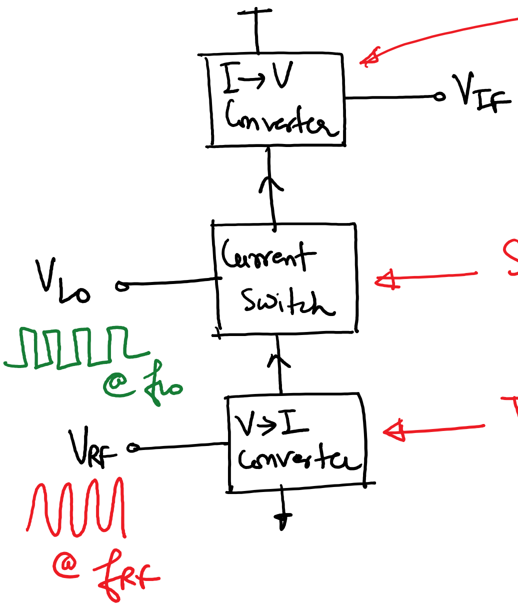
ECE 513- Lecture 25

Thursday, November 15, 2018 9:30 AM

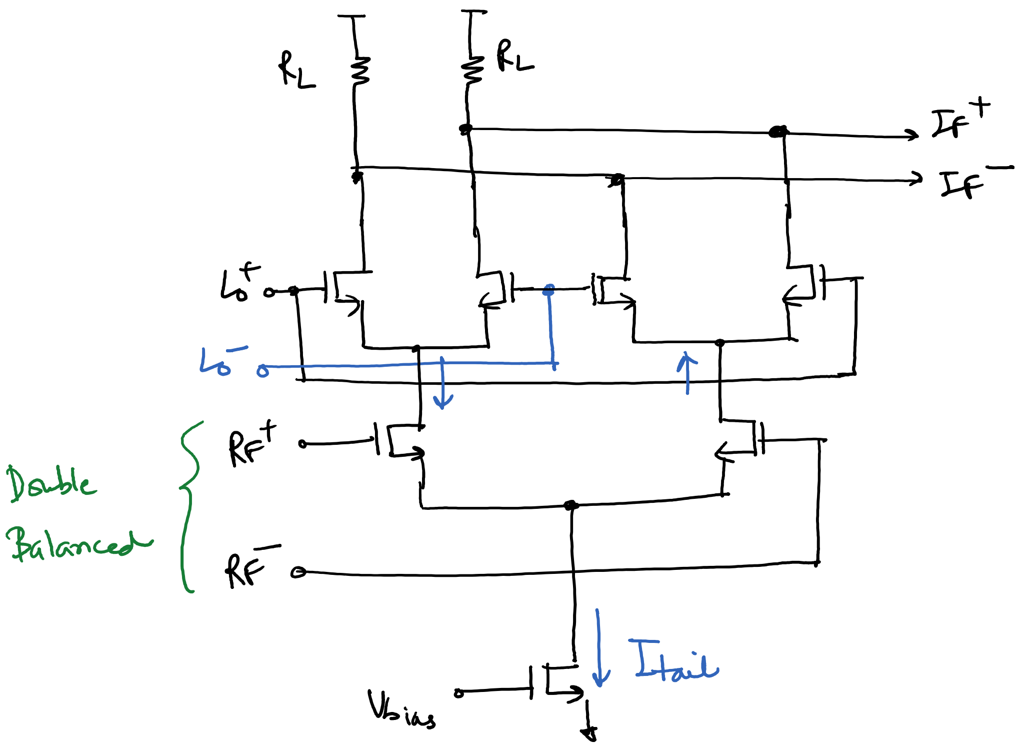
Double-balanced Gilbert Cell Mixer Topology

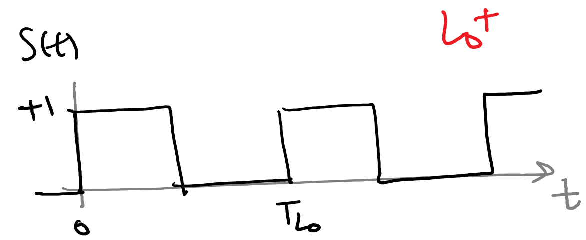


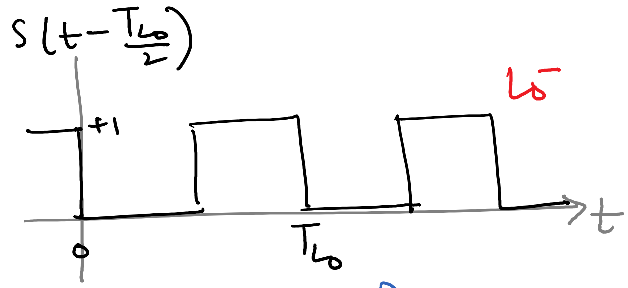
load → LC filter
↳ filter out the undesired mixing products

Switching Quad (Two cross-coupled Diff-pairs)

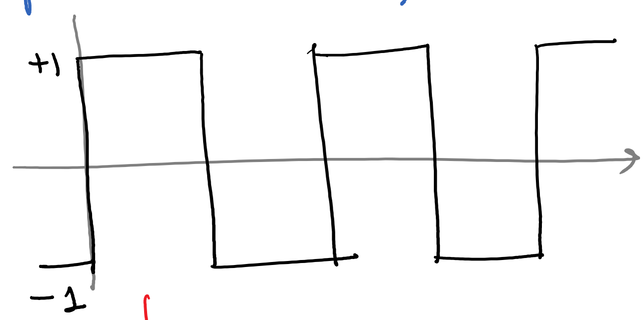
Transconductor (Diff-pair) → G_m

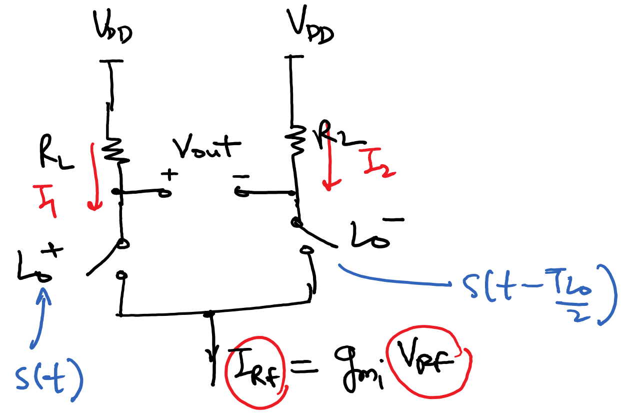






$p(t) = S(t) - S\left(t - \frac{T_{LO}}{2}\right)$





$I_1 = I_{RF} \cdot S(t)$

$I_2 = I_{RF} \cdot S\left(t - \frac{T_{LO}}{2}\right)$

$\rightarrow V_{out} = (V_{DD} - I_1 R_L) - (V_{DD} - I_2 R_L)$

$= I_{RF} \cdot R_L \cdot \left[S\left(t - \frac{T_{LO}}{2}\right) - S(t)\right]$

$\rightarrow V_{out}(t) = I_{RF} \, R_L \cdot p(t)$

LO waveform

waveform that toggles between +1 and −1

Fourier expansion

→ fundamental amplitude $= \frac{4}{\pi}$

$V_{out}(t) = I_{RF}(t) \cdot R_L \cdot \frac{4}{\pi} \cos(\omega_{LO} t) + \dots$ higher harmonic terms

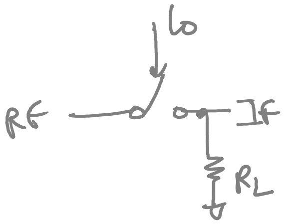
→ $g_{m1} V_{RF} \cos(\omega_{RF} t)$

After multiplication & filtering of the $\omega_{LO} + \omega_{RF}$ term

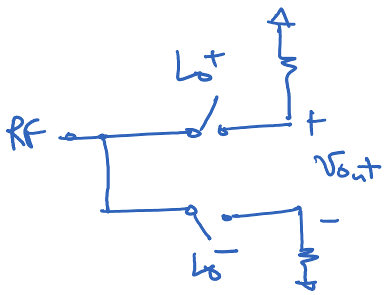
$$\Rightarrow V_{IF}(t) = \frac{2}{\pi} g_{m1} R_L \cdot V_{RF} \cdot \cos\left((\omega_{RF} - \omega_{LO}) t\right)$$

voltage Conversion gain

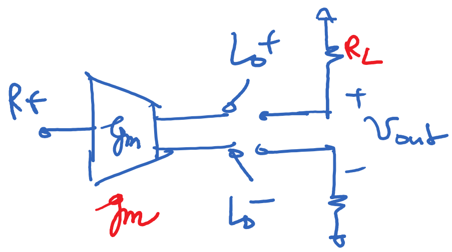
$$A_c = \frac{V_{IF_{pk}}}{V_{RF_{pk}}} = \frac{2}{\pi} g_{m1} R_L$$



$$A_c = \frac{1}{\pi}$$



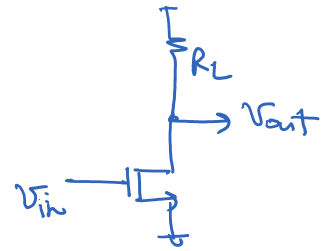
$$A_c = \frac{2}{\pi}$$



$$A_c = \frac{2}{\pi} g_m R_L$$

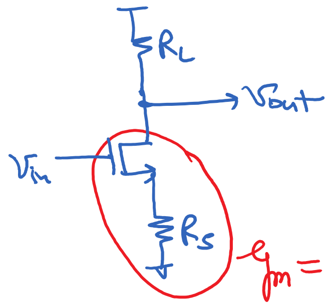
Gilbert Mixer

for increasing mixer linearity.



$A_v = g_m R_L$

Source degeneration

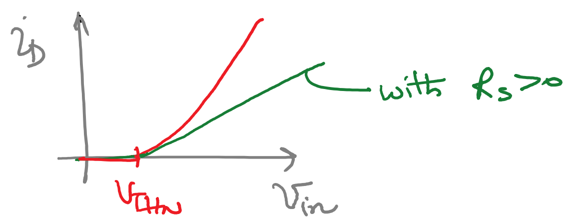


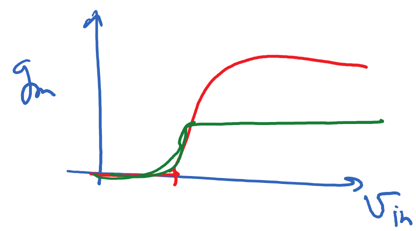
$$G_m = \frac{g_{m_1}}{1 + g_{m_1} R_S}$$

$$= \frac{1}{\frac{1}{g_{m_1}} + R_S}$$

for $g_{m_1} R_S >> 1$

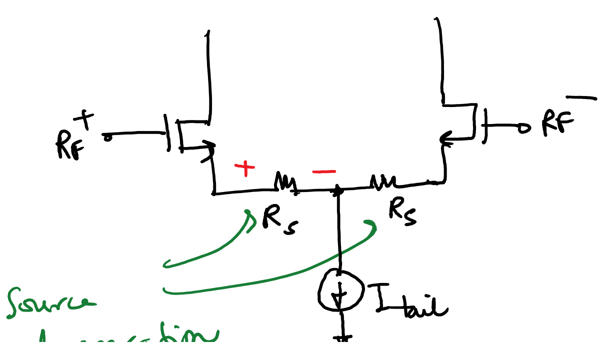
$$\simeq \frac{1}{R_S}$$



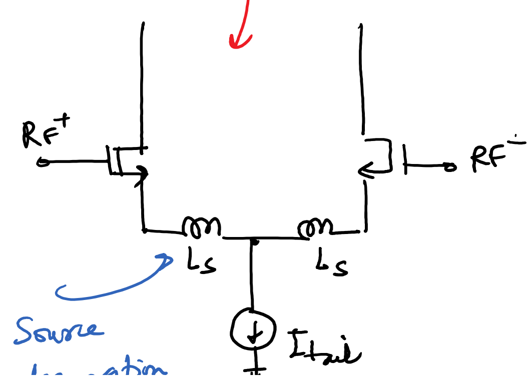


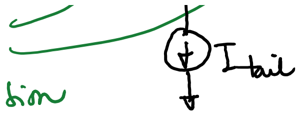
* Effective g_m drops but its a 'more linear' response

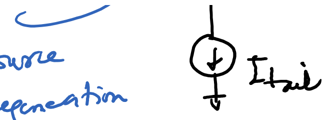
* Use source degeneration in the mixer to trade conversion gain with linearity.



Good for voltage headroom
frequency dependent





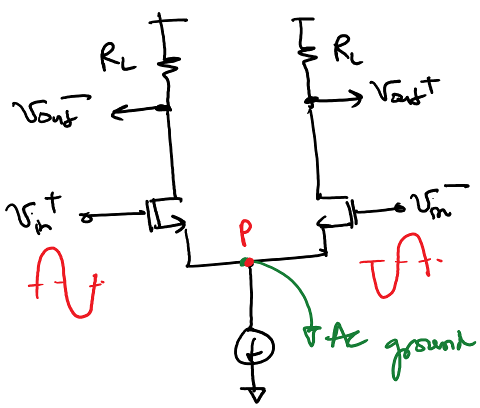


└ Can be part of the input match similar to the LNA.

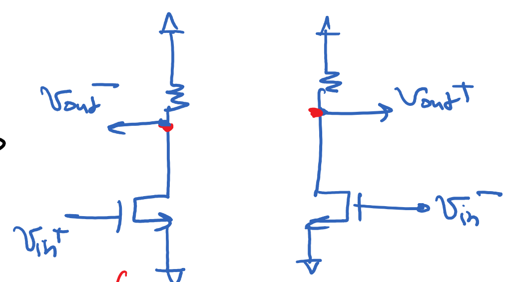
G_m will be $\dfrac{g_{m1}}{1+j\omega_{RF}L_s g_{m1}}$

* Similar to the matched LNA power gain, we can derive the power gain of the mixer that is matched at the RF port to Z_{in} & at the IF port to R_L

$$G_{c,max} = \frac{1}{2\pi}\,\frac{f_{T,eff}^2}{f_{RF}^2}\cdot\frac{R_L}{Z_{in}}$$

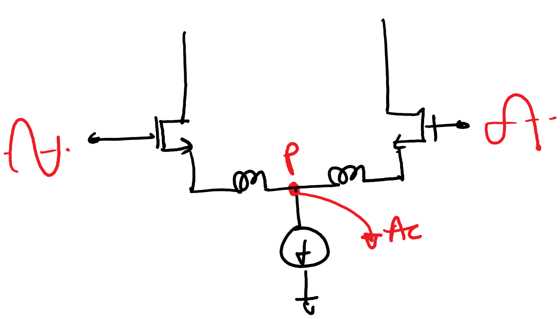


⇒

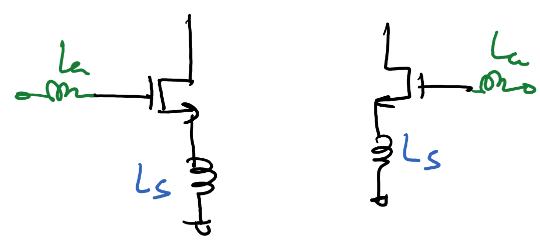


$A_v = g_{m1}R_L$

Differential Half Circuits



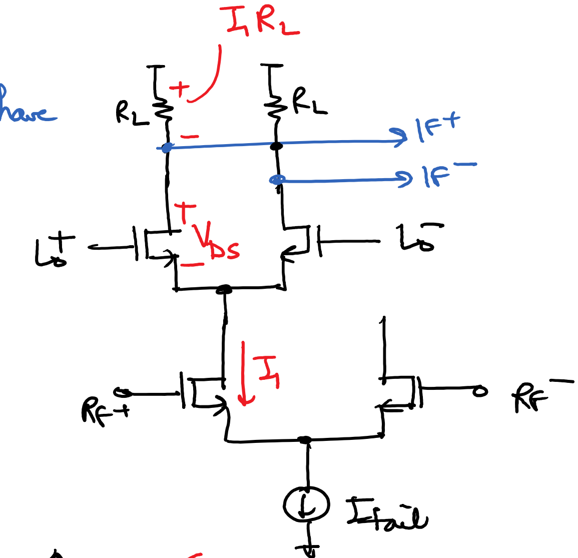
⇒

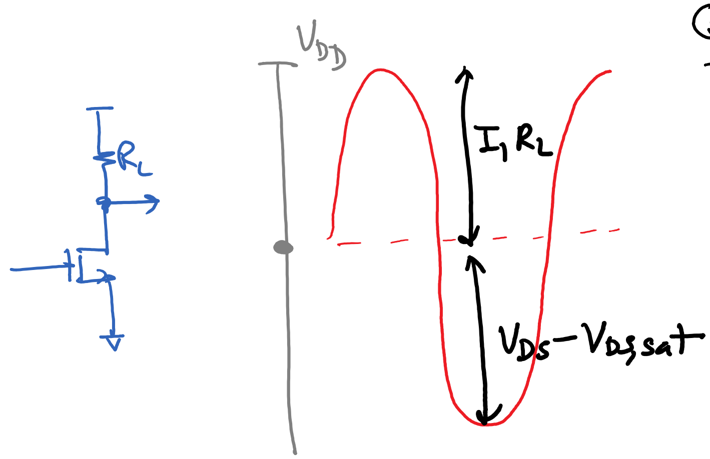


Gilbert Cell Mixer Linearity:

* depends upon the linearity of the transconductor (input diff-pair) and the V_{DS} of the mixing quad

* In a well-designed mixer, we should have $(V_{DS} - V_{DS,sat})$ of the mixing quad transistor equal to the voltage drop $I_1 R_L$, when the input is balanced





* G_m's linearity can be improved by resistive or inductive degeneration.
  ↳ amount of linearization ⇒ $\omega_{RF} \times L_S \times I_{Tail} \times A_{V_C}$

By comparing $V_{OMAX} = \min\{I_{TAIL} \cdot R_L,\ V_{DS_2} - V_{DS,sat}\}$ and (→ mixing Quad)

$\omega_{RF} \times L_S \times I_{Tail} \times A_{V_C}$

we can tell which part of the mixer limits linearity.

* Read Example 9.8 from the Book

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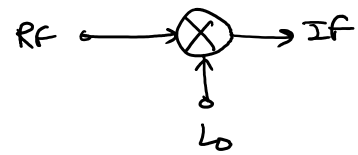
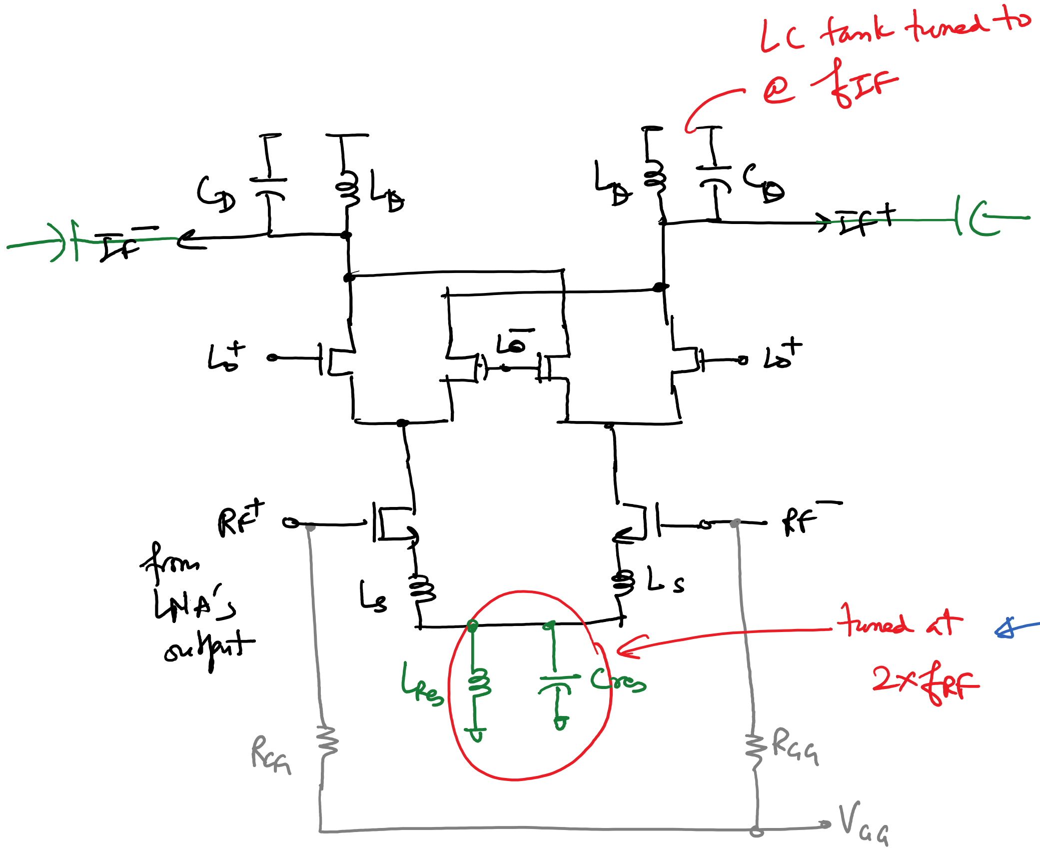
* Downconversion Mixer at 5GHz RF frequency, $f_{IF} = 1\,GHz$.

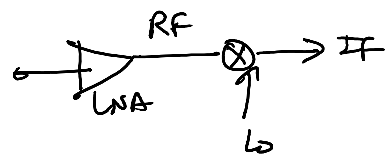
$f_{LO} = 4\,GHz \Rightarrow f_{IM} = 3\,GHz$

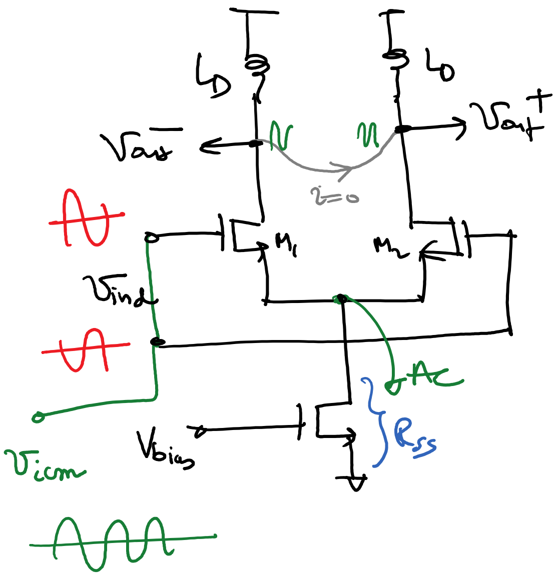


1) Low-noise transconductor, linear
2) mixing quad
3) an LO or RF trap (a bandreject filter centered at RF frequency) at the IF input

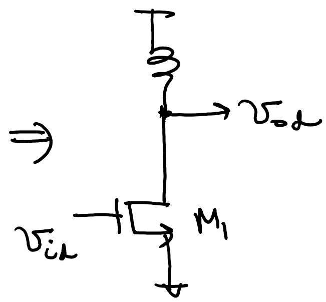


better common-mode rejection at even order harmonics of f_{RF}

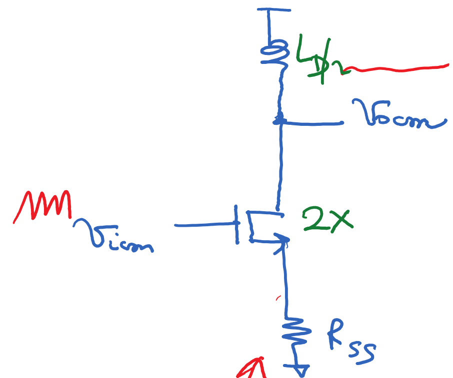




Differential half Circuit



Common-Mode Half Circuit

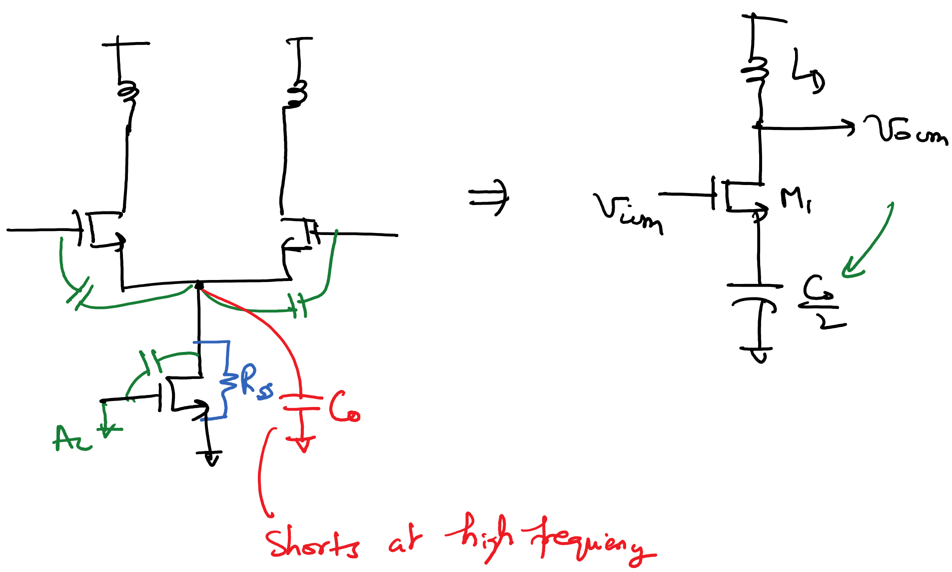


for $R_{SS} \to \infty$

⇒ common-mode gain → 0

⇒ Common-mode rejection

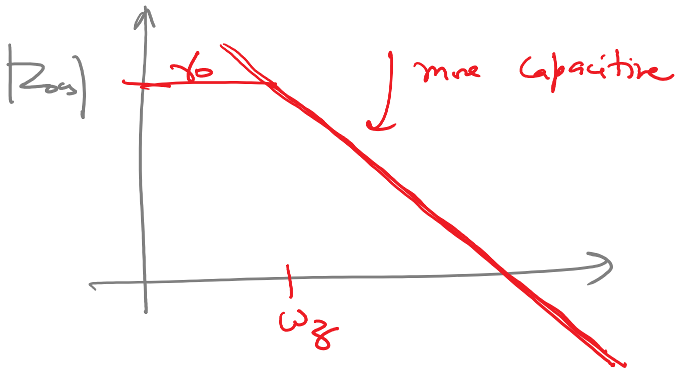
At high frequencies



output impedance of the current source

$$Z_{ocs} = \frac{r_0}{1 + s r_0 C_0} = \frac{r_0}{1 + s/\omega_z}$$

$$\omega_z = \frac{1}{r_0 C_0}$$

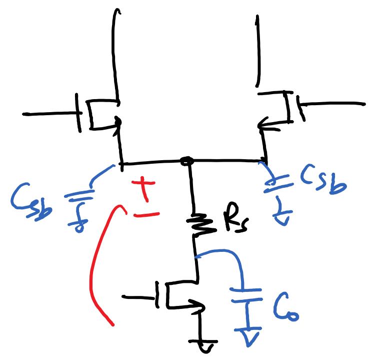


* In 65nm CMOS

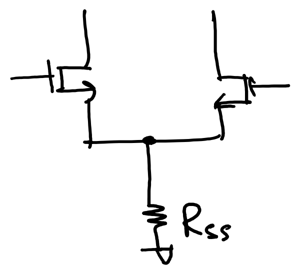
$$f_z = 17.7\ \text{GHz}$$

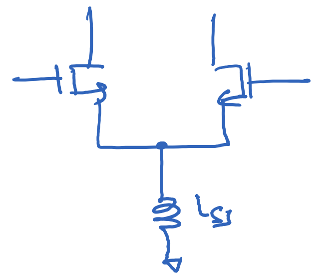
* Degrades CM rejection at high frequencies
  ↳ even-order harmonics of RF (as well as LO) will show up at the mixer output.

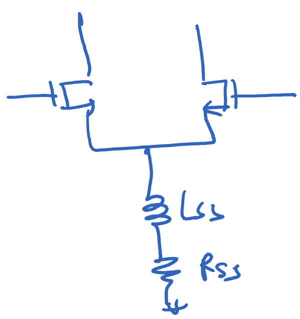
* Solutions to improve CM-rejection

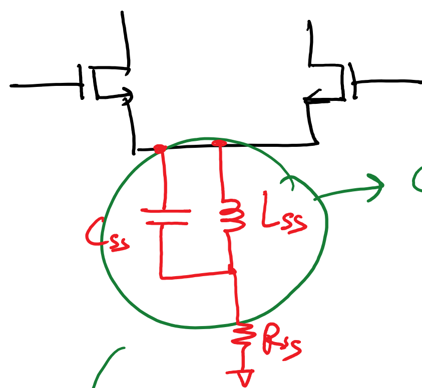


DC voltage headroom









Can be tuned to $2f_{RF}$

improves IIP_2 performance of the mixer