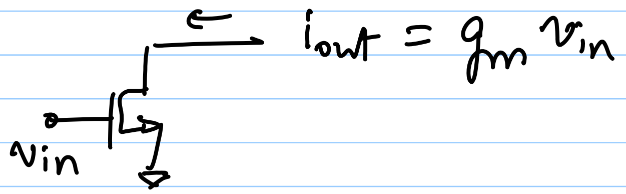
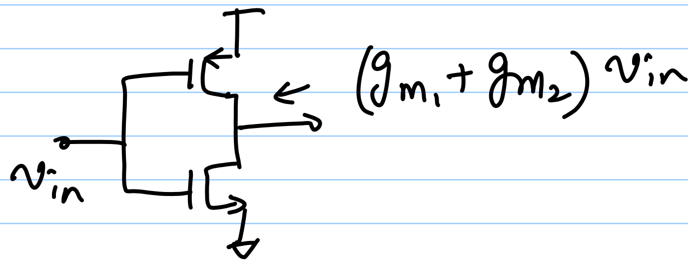
Lecture 19: LNA Design (final); Introduction to Mixers

Other ideas to explore (LNAs)

1) Current re-use:





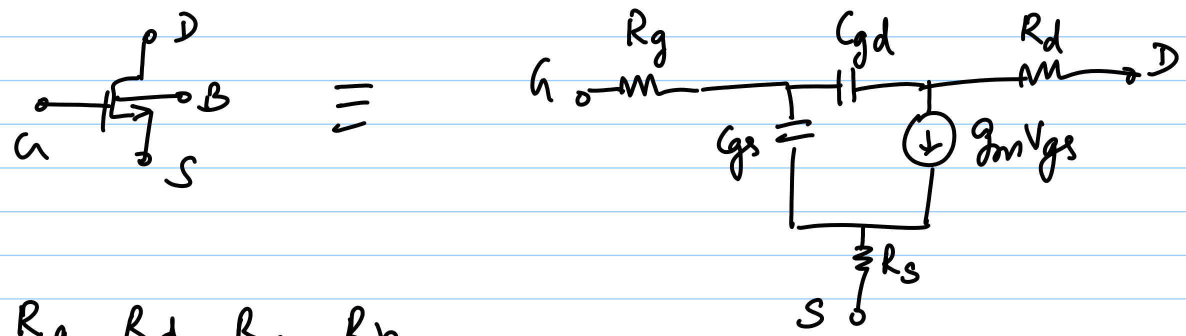
2) Feedback:
   * to match $R_{in} = 50\Omega$
   * to improve IIP_3 (linearity)

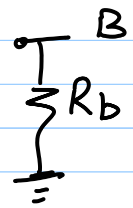
   issues:
   → NF may increase substantially
   → Stability may worsen

Other general rules of thumb

* Start off with same W & L for cascode device; usually cascode gate $= V_{DD}$
* Start with $f_T \geq 10\times$ operating freq.
* Model noise accurately (e.g. model may use $\gamma = 2/3$ & $\delta = 0$).
* Hand calculations are approximations only, so use simulation tools effectively:
  → Plot g_m, f_T and Γ vs. I_{bias} and W
  → Plot NF vs. current density
  → Usually, $NF_{opt.} \neq S_{21\,opt.} \neq IIP_{3\,opt.}$

Extrinsic sources of noise (MOS)





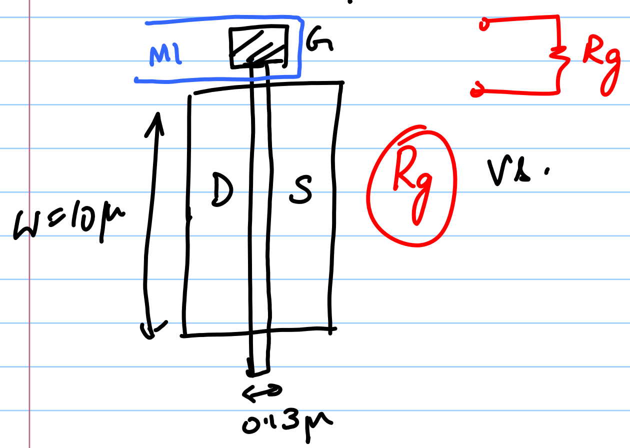
* R_g, R_d, R_s, R_b contribute thermal noise

solution: use sound RF layout techniques

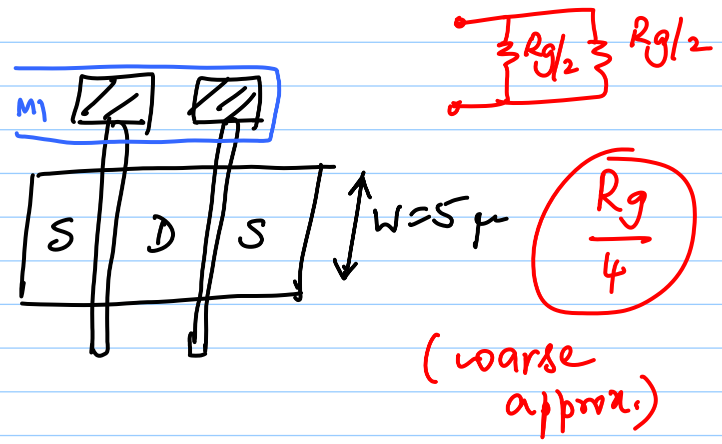
1) R_g — use multifinger devices to reduce R_g

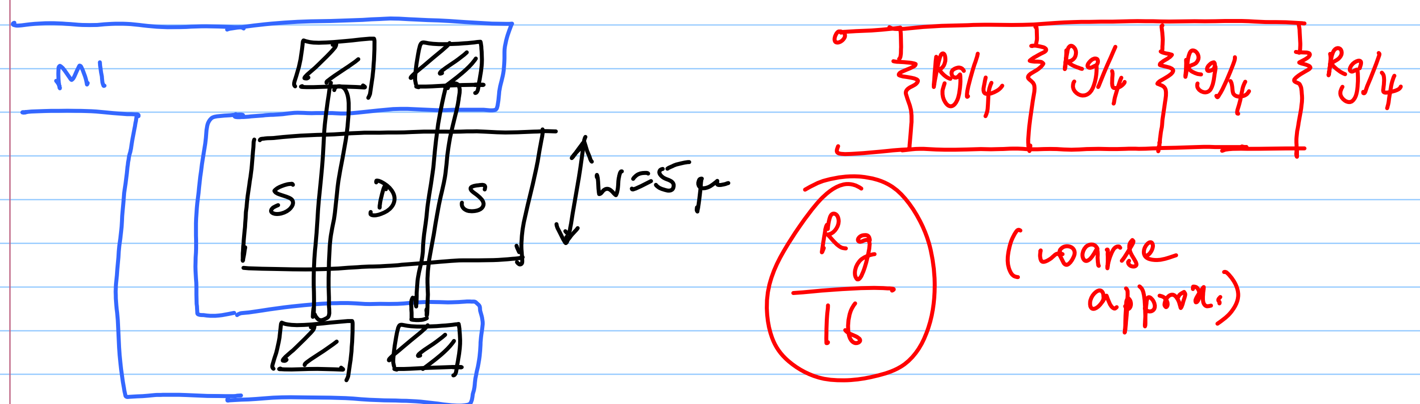
— contacts on both sides of gate

e.g. $\frac{W}{L} = \frac{10\mu}{0.13\mu}$; $R_{metal} << R_{poly}$



vs.





Accurate expression: (takes distributed effects into account)

$$R_g = K \cdot \frac{R_{sh} \cdot W}{n^2 L} \quad \begin{cases} K = \frac{1}{3} \text{ for 1-side gate contact} \\ \;\;= \frac{1}{12} \text{ for 2-sided gate contact} \end{cases}$$

→ R_{sh} = sheet resistance

→ n = number of fingers

2) R_b — use more number of substrate contacts

— thermal noise of R_b can modulate backgate of MOS

— can impact gain & NF

$$\overline{i_{nd,sub}^2} = 4kT R_b \cdot g_{mbs}^2 \Delta f$$

Introduction to Mixers:

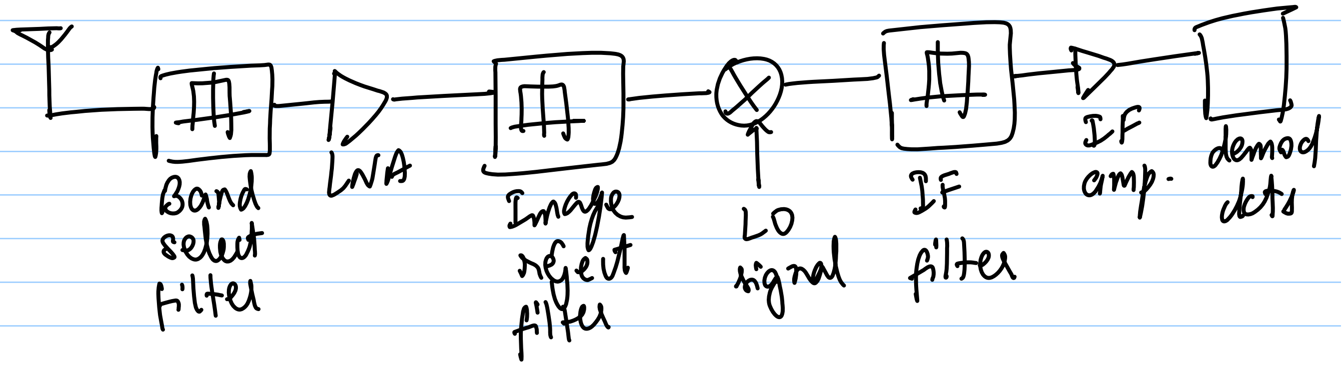
* Mixers are used for freq. translation

Tx → upconversion of BB signals to IF/RF

Rx → down-conversion of RF signals to IF/BB

Down-conversion mixers

Superhet. receiver



Simple mixer: RF → ⊗ → IF (LO)

$$x_{RF}(t) = A_{RF}\cos\omega_{RF}t \quad \Big\} \quad x_{IF}(t) = x_{RF}(t)\cdot x_{LO}(t)$$
$$x_{LO}(t) = A_{LO}\cos\omega_{LO}t$$

$$x_{IF}(t) = (A_{RF}\cos\omega_{RF}t)\cdot(A_{LO}\cos\omega_{LO}t)$$
$$= \frac{A_{RF}A_{LO}}{2}\left[\underbrace{\cos(\omega_{LO}-\omega_{RF})t}_{\text{desired IF term}} + \cos(\omega_{LO}+\omega_{RF})t\right]$$

Metrics

1) G_c = conversion gain = $\dfrac{\text{IF amplitude (desired IF)}}{\text{RF amplitude}}$

$$G_c = \frac{A_{RF}A_{LO}/2}{A_{RF}} = \frac{A_{LO}}{2}$$

$G_c < 1$ may be ok in several cases (depending on NF)

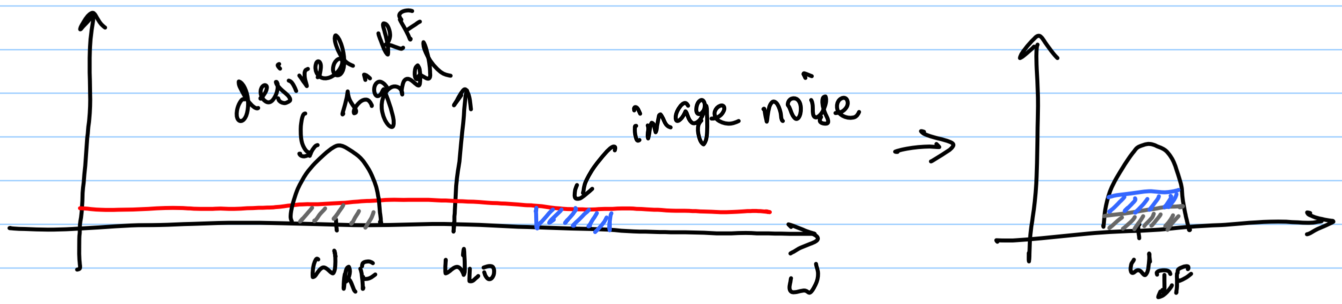
⇒ Passive Mixers

2) Noise Figure NF

$$NF = \frac{\text{SNR @ RF port}}{\text{SNR @ IF port}}$$

* Beware of image frequencies when computing NF of mixers

→ Even if there is no image signal @ ω_{IM}, noise from ω_{IM} still contributes to NF!



* NF_{DSB} is measured with useful RF signal at both ω_{RF} & ω_{IM} (i.e. $\omega_{LO} \pm \omega_{IF}$)

* NF_{SSB} is measured with useful RF signal only at one freq. (either $\omega_{LO}+\omega_{IF}$ or $\omega_{LO}-\omega_{IF}$)

$\Rightarrow$ $NF_{SSB} = NF_{DSB} + 3dB$ (noise power adds as mean-square)

$\Rightarrow$ Check carefully to see which NF is quoted!

NF_{SSB} is the accurate metric in most cases

* Note that even if mixer is <u>noiseless</u>,

$NF_{SSB} = 3dB$!

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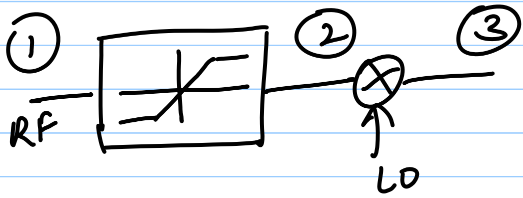
typical values are

$NF_{SSB} \sim 10-15dB$

$\Rightarrow$ LNA needs to precede mixer to keep $NF_{tot.}$ low.

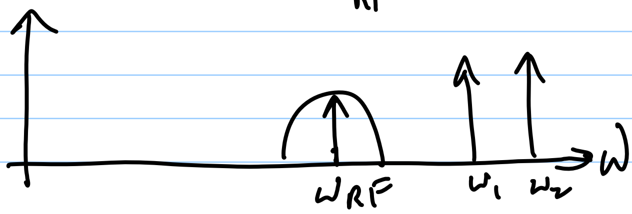
3) Linearity : measured as IIP_3/OIP_3 at appropriate frequency (RF/IF)

RF path non-linearity:



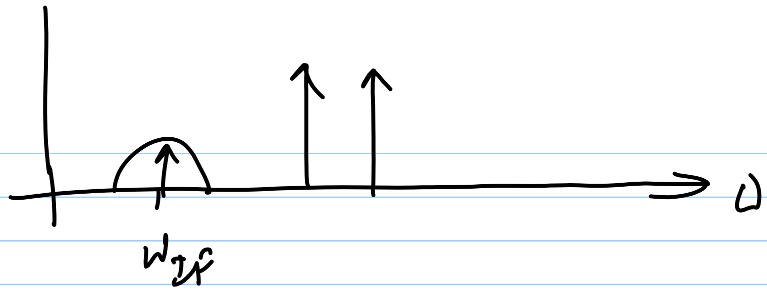
①

②



IM_3 component falls at desired ω_{RF}

③



* Cubic non-linearity can cause problems even with a single input!

e.g. AM radio

$IF = 455\,kHz$; $f_{ch} = 910\,kHz$

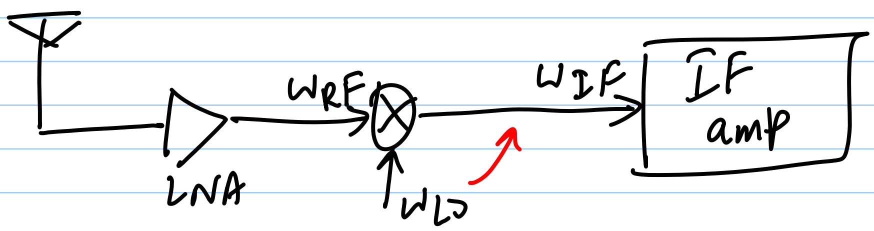
$\Rightarrow f_{LO} = 1365\,kHz$

cubic nonlinearity – generates $(2\omega_{RF} - \omega_{LO})$ term

In this case, $2\omega_{RF} - \omega_{LO} = 455\,kHz = \omega_{IF}$!

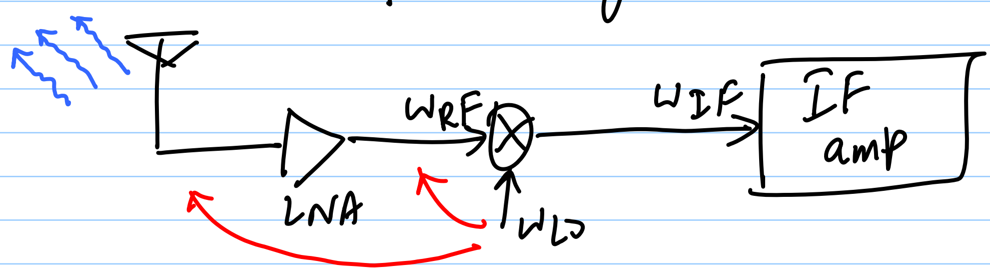
4) Isolation:

(a)



* $\omega_{LO} \gg \omega_{RF}, \omega_{IF}$
* LO – IF feed through would saturate IF amp.

(b)



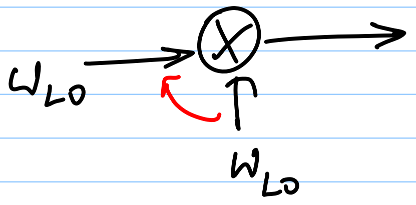
LO – RF feed through (reverse isolation)

* Re-radiation of LO & its harmonics
* Usually, $A_{LO} \gg A_{RF}$

Direct-conversion (Homodyne) receiver:

$\omega_{RF} = \omega_{LO}$, $\omega_{IF} = 0$

we want only ω_{RF} @ BB



"self-mixing"

→ low-freq. term that depends on LO only

→ can be larger than desired RF signal

5) Spurs

Mixers, by nature produce a bunch of freq. components

* Undesired freq. components @ mixer output are called spurious signals or 'spurs'
* Highly tedious in practice:
  if there are m & n harmonic numbers @ RF & LO frequencies respectively,
  $f_{spur} = m f_{RF} + n f_{LO}$ for all combinations & signs of m & n