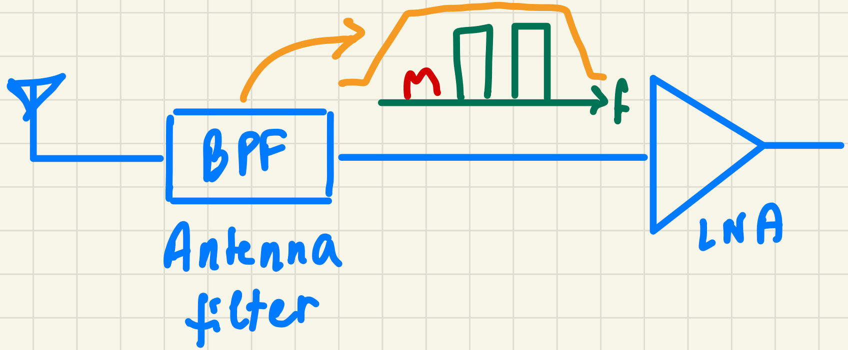
# RF Circuit Design

L21

# Transceivers Architectures

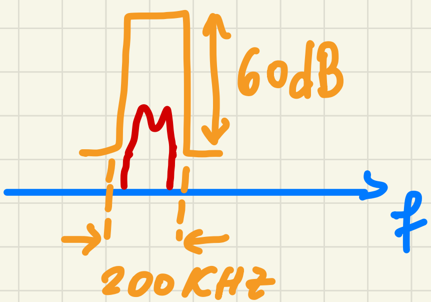
## RX Architectures

- Heterodyne architecture
  - Single IF
  - Double IF
- Direct-conversion or zero-IF RX
- Sliding IF
- IF sampling




Antenna filter attenuates OUT-OF-BAND interferers

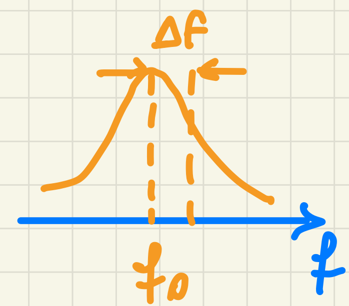
Channel selectivity in wireless systems in order of 60 dB




• LC filter (2nd order):

$$|T(j\Delta f)| \approx \frac{f_0/2Q}{\Delta f} = f_{bw}/\Delta f$$

$\Delta f \gg f_0/2Q$



$$-60\,dB \Rightarrow |T| = 10^{-3} = \frac{f_0}{\Delta f}\,\frac{1}{2Q}$$

2GHz    100 KHz

$$\Rightarrow Q = \frac{\cancel{2}\cdot 10^9}{10^5}\cdot\frac{1}{\cancel{2}}\,\frac{1}{10^{-3}} = 10^7 \Rightarrow \text{too large!}$$

not feasible

$$f_{bw} = \frac{f_0}{2Q} = \frac{2\cdot 10^9}{2\cdot 10^7} = 100\,Hz$$

$\rightarrow$ too narrow

- 2n-th order filter: Butterworth BPF

50 KHz

$$|T(j\Delta f)| \approx \left(\frac{f_{bw}}{\Delta f}\right)^n = 10^{-3} \Rightarrow n = 10$$

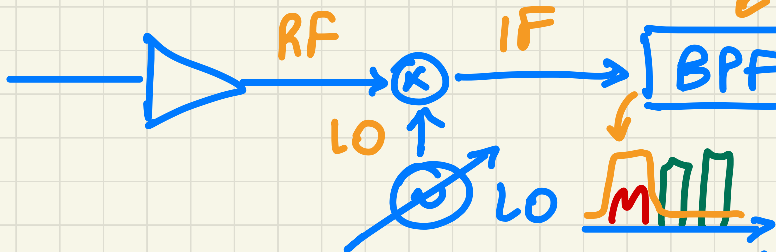
(20 poles)

100 KHz

$\Rightarrow$ Channel selectivity unfeasible at RF

Solution: Heterodyne RX

offchip SAW filter



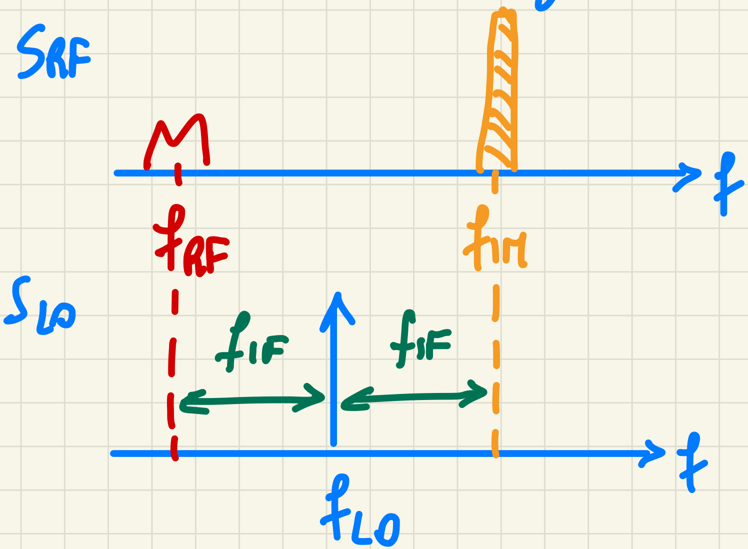

50 ÷ 60 dB selectivity at center frequency ≈ 10÷100 MHz

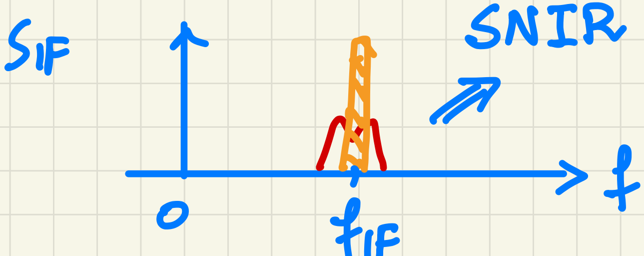
2 advantages:

- IF frequency is lower than RF freq.
- IF filter does not need to be tunable

$\rightarrow$ low IF to improve selectivity

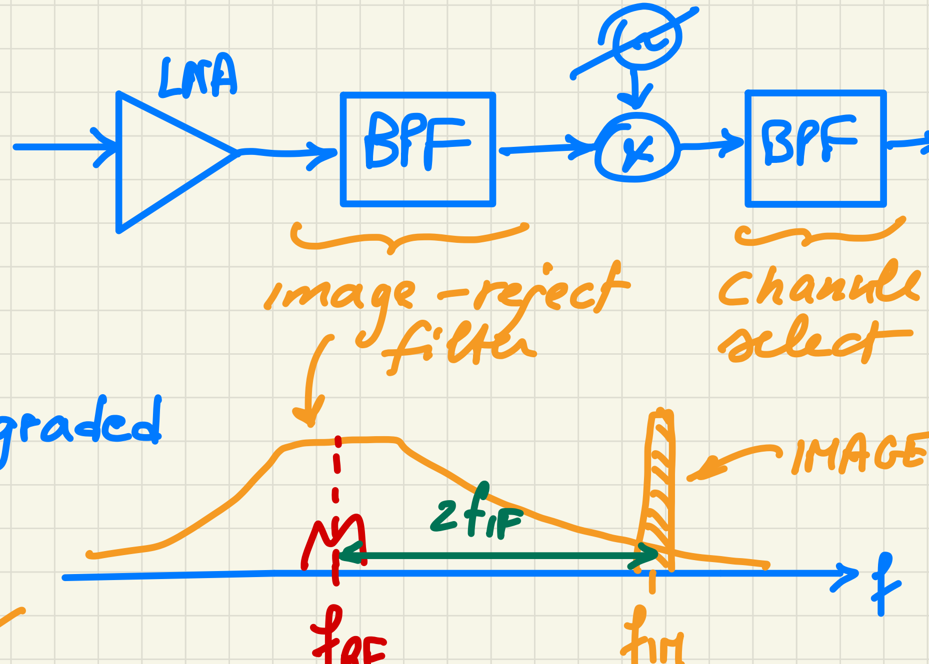
# Issue: Image Problem




SNIR degraded

Solution: IR filter



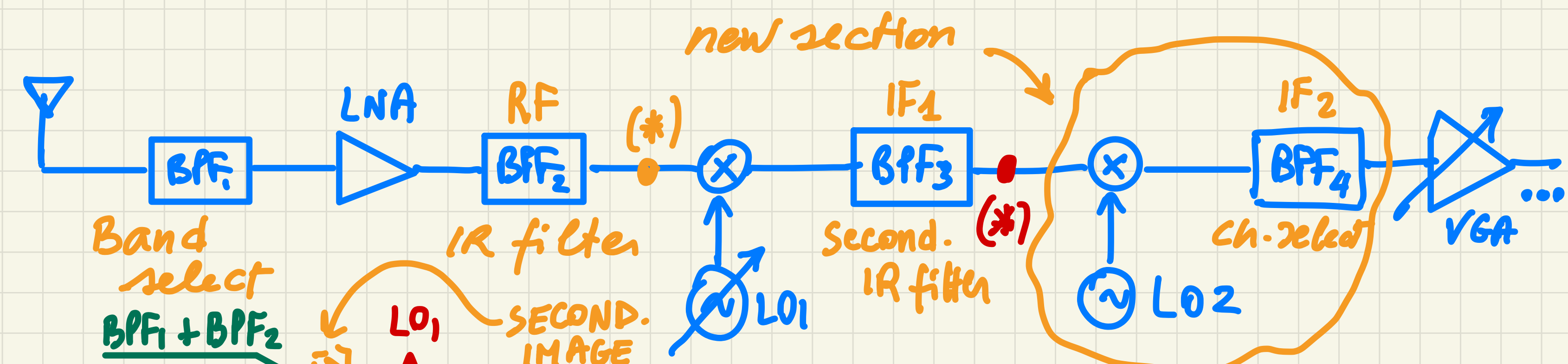

high IF to improve image rej

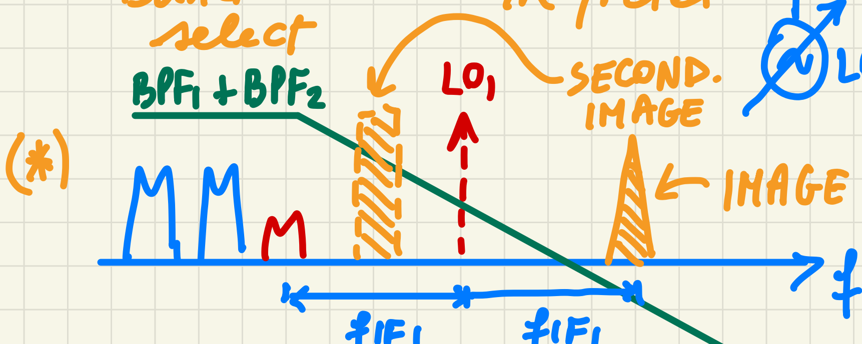
trade off : $\begin{cases} \bullet \text{ RX sensitivity} \leftrightarrow \text{image} \\ \bullet \text{ RX selectivity} \leftrightarrow \text{in-band interferers} \end{cases}$

high $f_{IF}$

low $f_{IF}$

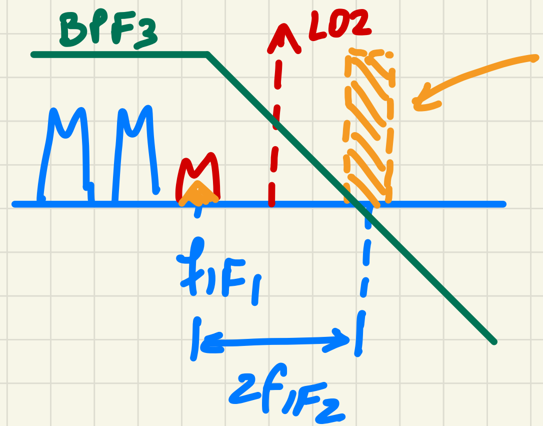
Solution to relax trade-off: <u>Dual-IF Architect.</u>




- Large $f_{IF_1}$ : relaxes IR ($BPF_2$)
- Small $f_{IF_2}$ : relaxes ch. sel. ($BPF_4$)

(*)

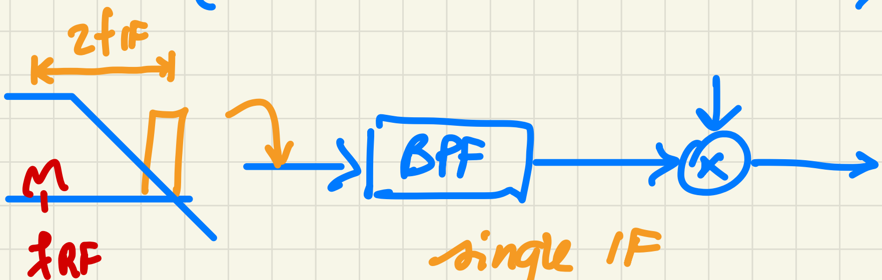



BPF3 :

center frequency ($f_{IF_1}$) which is lower than $f_{RF}$ ✓

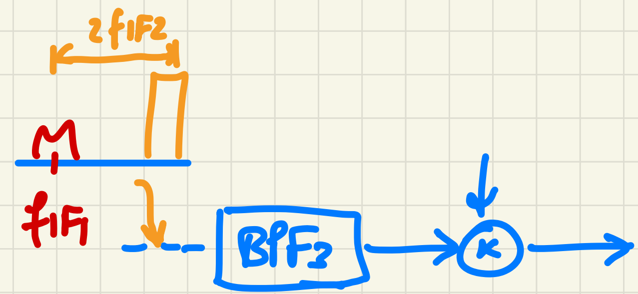
compared to single-IF architect.

the secondary image problem is more relaxed (BF3 is more relaxed)




single IF

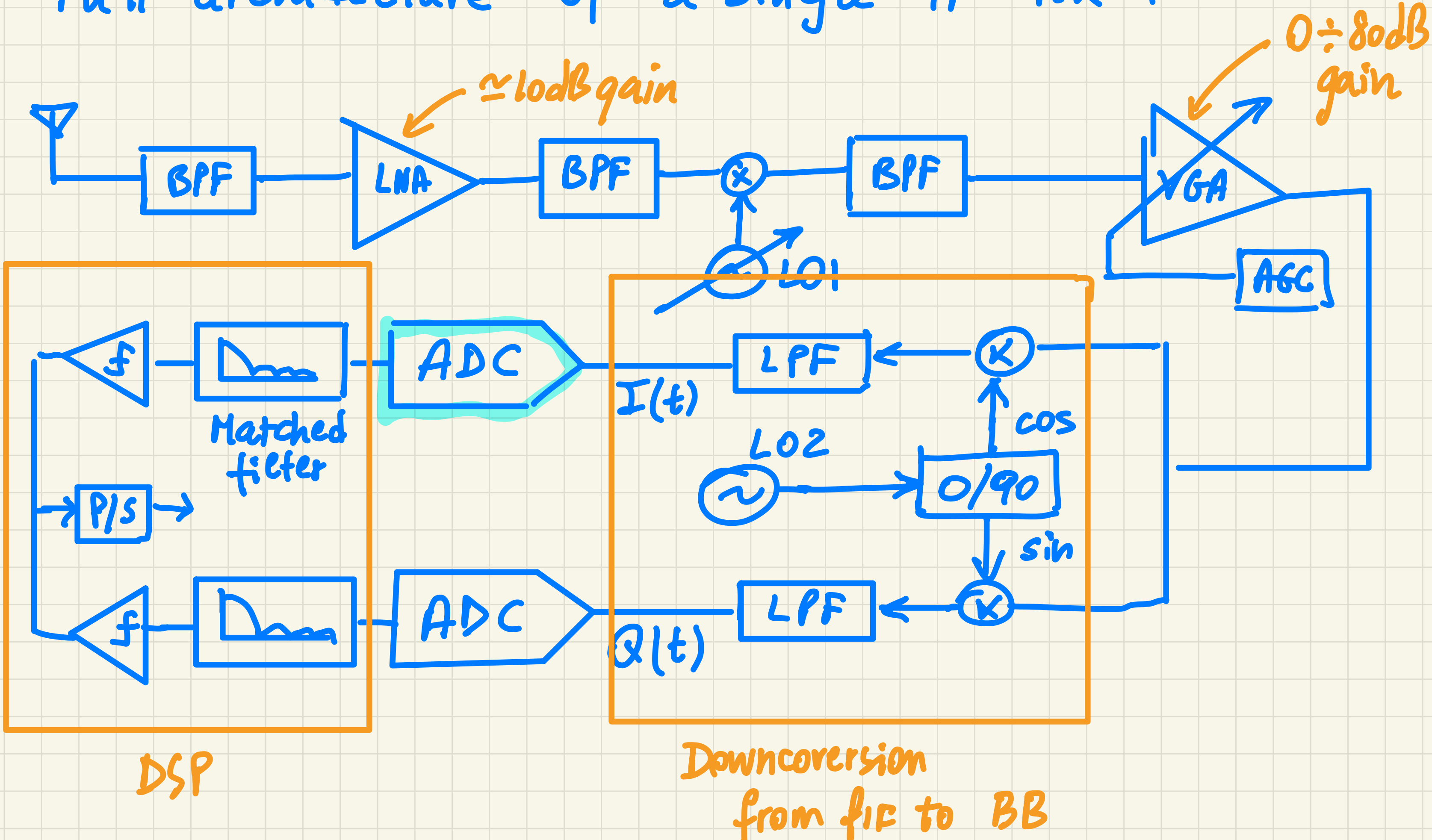
$$Q \div \frac{f_{RF}}{2f_{IF}}$$

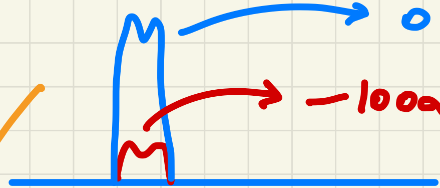



Dual IF

$$Q \div \frac{f_{IF1}}{2f_{IF2}}$$

Full architecture of a single-IF RX :





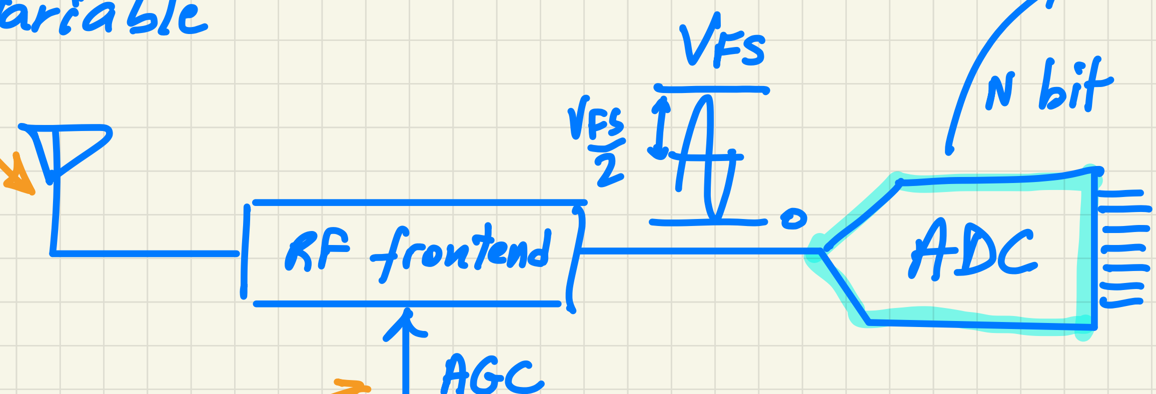
0 dBm → 600 mVpp (50Ω)

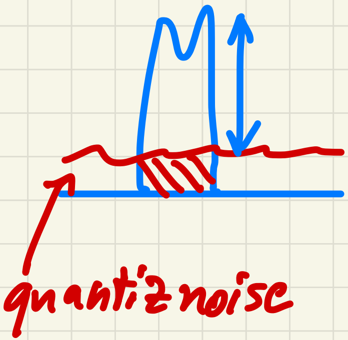
−100 dBm → 6 μVpp (50Ω)

wanted signal power is extremely variable

ADC quantization noise

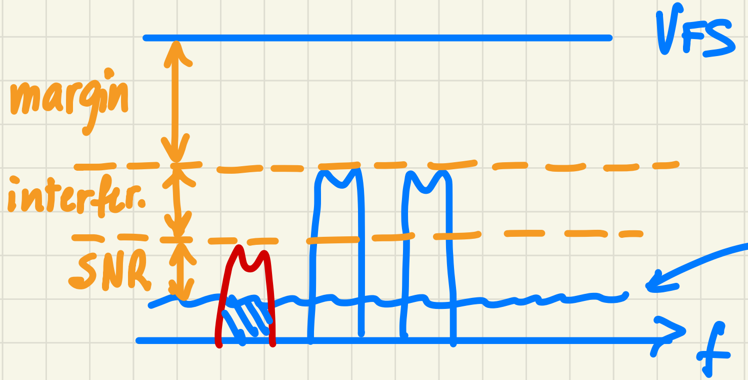
$$DR_{dB} = 6.02 \cdot N + 1.76$$

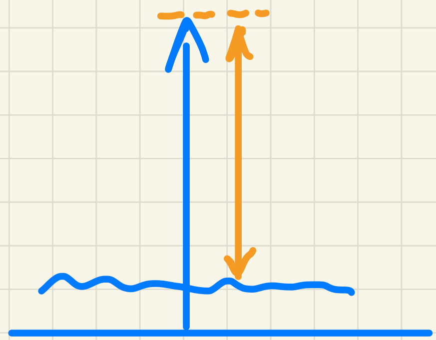



automatic gain control

$$DR = \frac{P_s}{P_q}$$



DR = SNR + Unfiltered interfer. ratio +

requirement

+ margin (AGC errors, fading, ...)

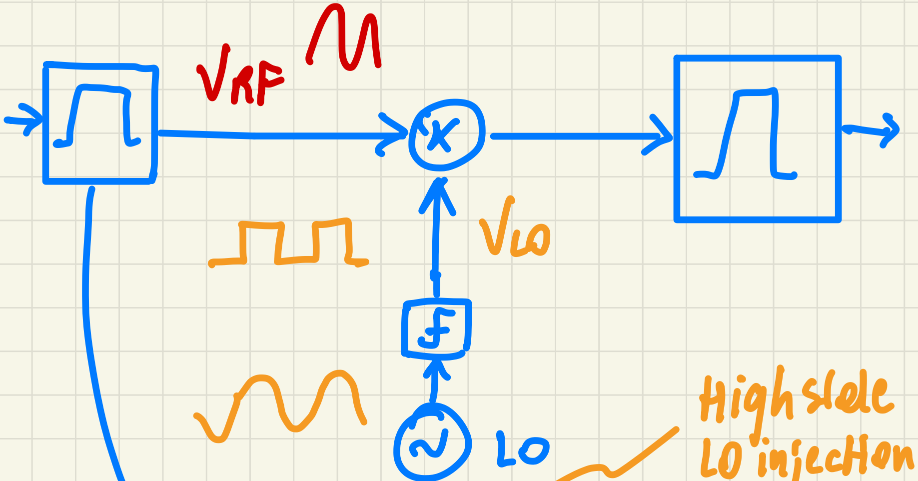
e.g. SNR = 12 dB

Unfiltered inter. = 26 dB $\Rightarrow$ DR = 60 dB

Margin = 22 dB

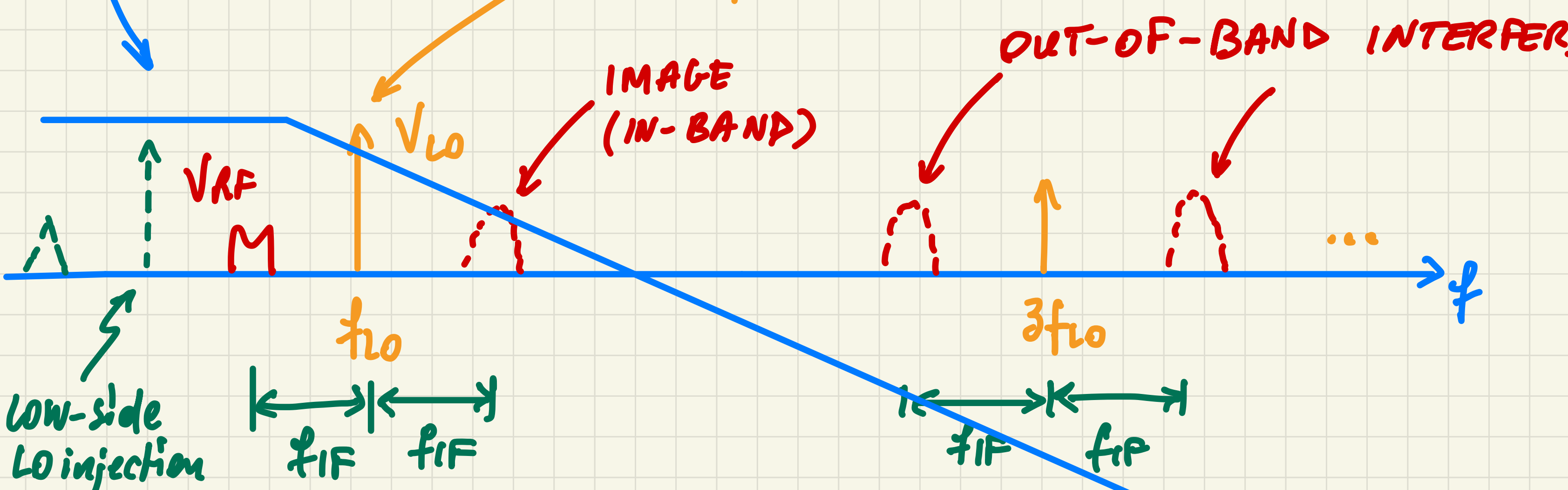
$\Downarrow$

N = 10 bit (ENOB)

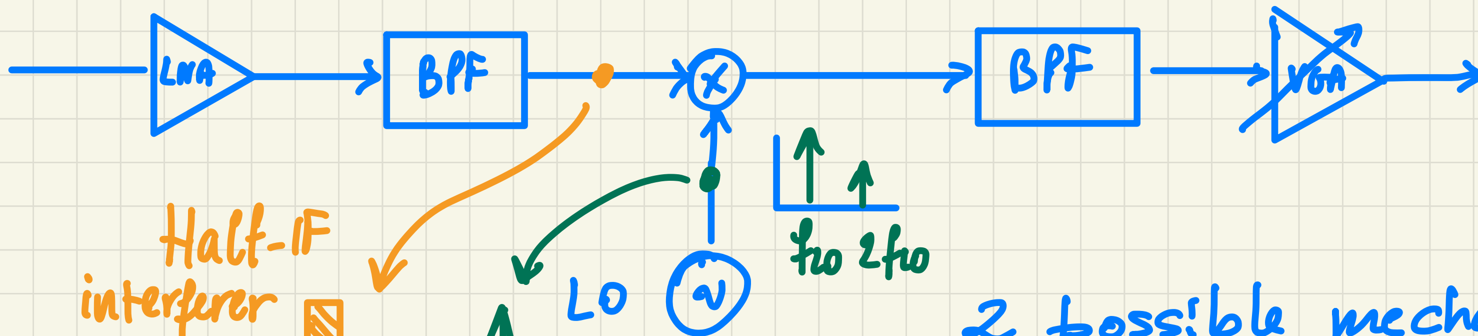


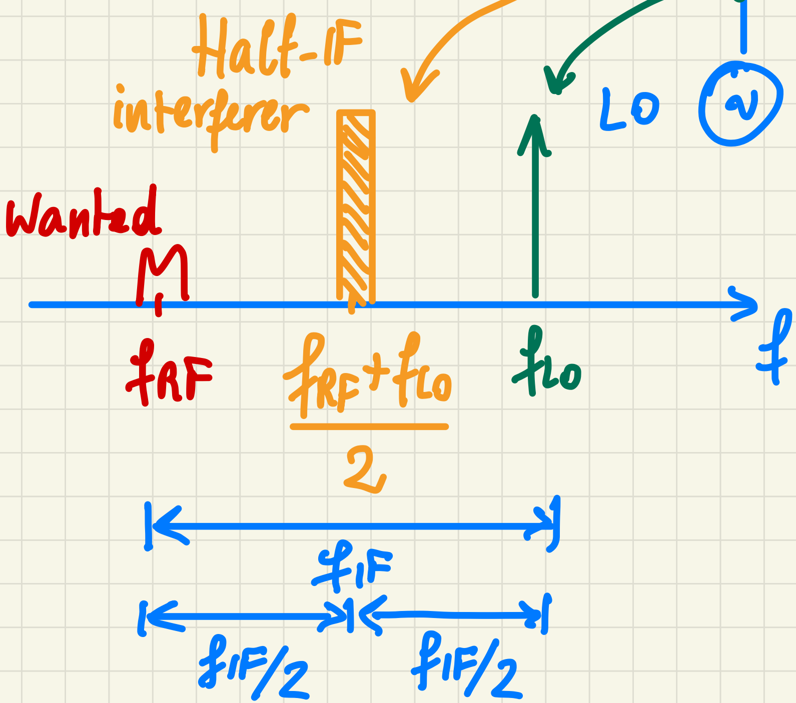

mixer

vs. analog multipl.



# Issue : Half-IF Problem

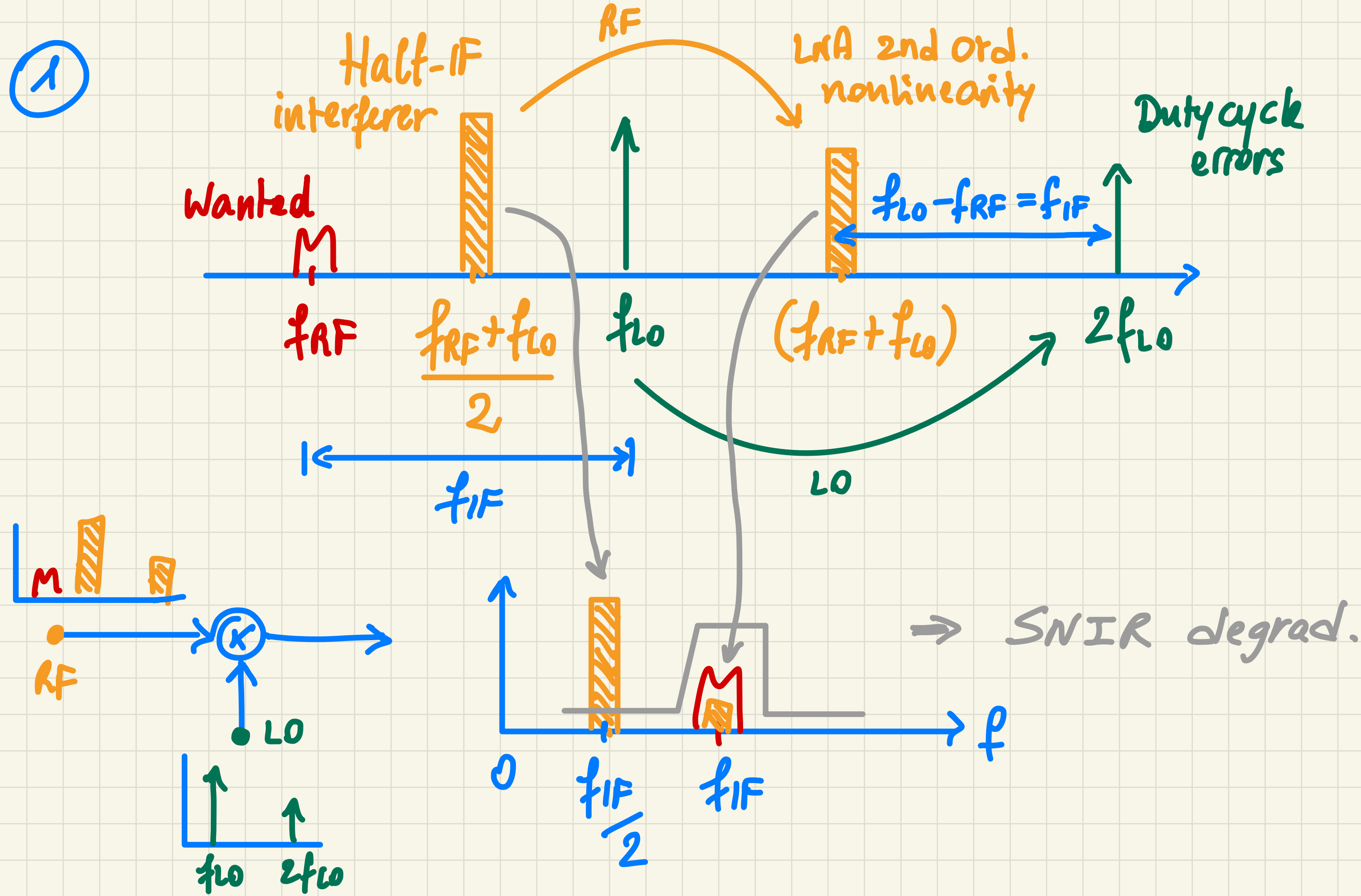


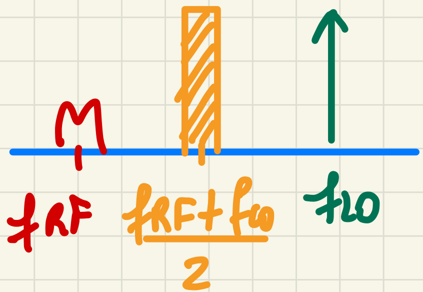

2 possible mechanisms

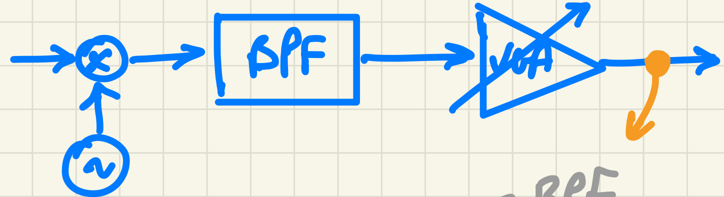
1. LO 2nd harmonic + LNA 2nd ord. nonlin.

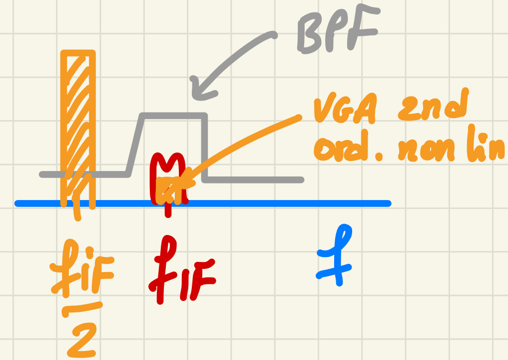
2. VGA 2nd ord. nonlin.


1
Half-IF interferer
RF
LNA 2nd ord. nonlinearity
Duty cycle errors
Wanted
$f_{LO} - f_{RF} = f_{IF}$
$f_{RF}$
$\frac{f_{RF}+f_{LO}}{2}$
$f_{LO}$
$(f_{RF}+f_{LO})$
$2f_{LO}$
$f_{IF}$
LO
RF
LO
$f_{LO}$
$2f_{LO}$
0
$f_{IF}/2$
$f_{IF}$
f
→ SNIR degrad.

2

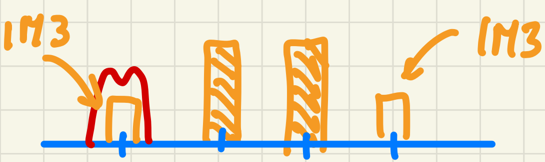


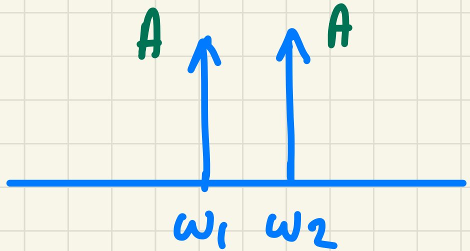



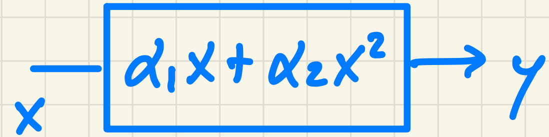

$$2 \cdot \frac{f_{IF}}{2} = f_{IF}$$

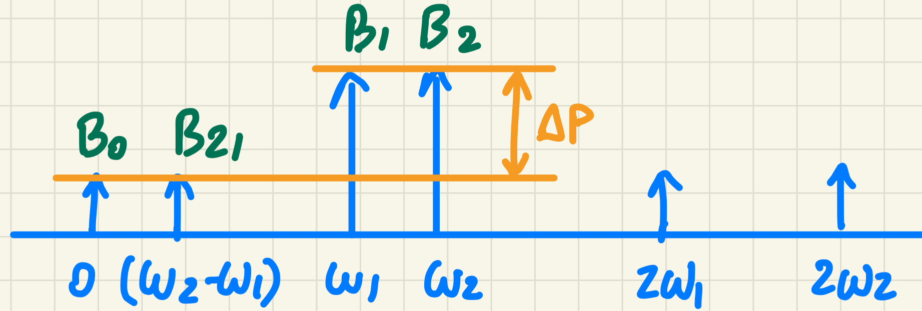
3rd ord. non linearity



# IIP2

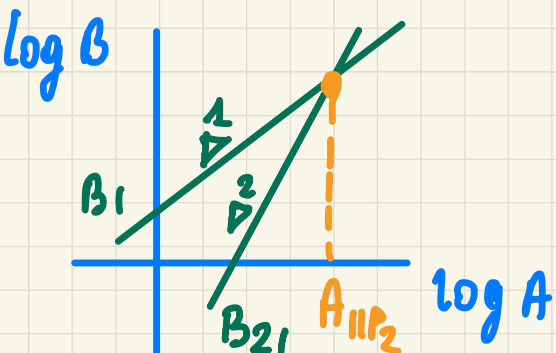


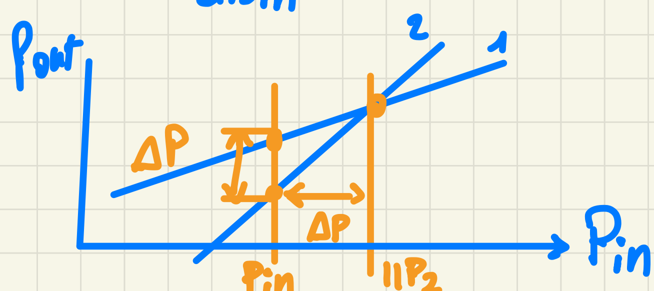




$$B_1 = B_2 = \alpha_1 A$$

$$B_{21} = \alpha_2 A^2 = B_0$$




$$IIP_2 \Big|_{dBm} = P_{in} \Big|_{dBm} + \Delta P \Big|_{dB}$$

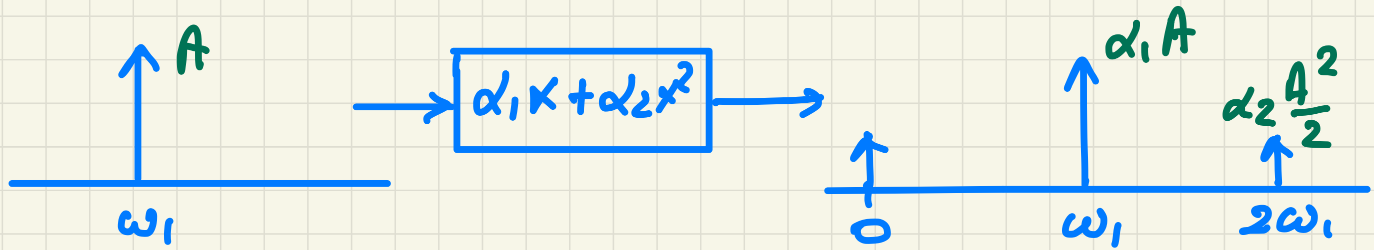



$$B_{21} = B_1$$

$$\alpha_2 A^{\cancel{2}} = \alpha_1 \cancel{A}$$

$$A_{IIP_2} = \frac{\alpha_1}{\alpha_2}$$

HD2




$$HD_2 = \frac{\alpha_2 \cancel{A^2}/2}{\alpha_1 \cancel{A}} =$$

$$= \frac{1}{2} \cdot \frac{A}{A_{IIP_2}}$$

$$\Downarrow$$

$$HD_2\big|_{dB} = P_{in}\big|_{dBm} - IIP_2\big|_{dBm} - 6\ dB$$

$$\alpha_1 A \cos\omega_1 t + \alpha_2 A^2 \cos^2\omega_1 t = \alpha_1 A \cos\omega_1 t + \alpha_2 A^2 \cdot \frac{1+\cos 2\omega_1 t}{2}$$